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D3.5.3 v1.0

Final assessment of relaying concepts for all CGs scenarios under consideration of related WINNER L1 and L2 protocol functions

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Abstract:

The deliverable is the continuation of the work presented in the WINNER II deliverables D3.5.1 and D3.5.2. The focus of this document is to apply methodologies for performance and cost assessment to relay based deployment. The refinement of WIINER relaying concept will be performed combining contributions from all previous deliverables, both in phase I and II of the project, and will be delivered in a separate document at the end of the project.

Keyword list:

Relaying, multi-hop, RRM, protocols, protocol architecture, cooperative relaying, network deployment

Disclaimer:

Executive Summary

The focus of this document is to apply methodologies for performance and cost assessment to relay based deployment.

In particular, the e2e performance assessment is conducted according to the methodology identified in [WIN2D6137] and in the concept groups [WIN2D6133-5]. The following assessment criteria have been measured: spectral efficiency, maximum number of supported users and delay once the satisfied user criterion is being met, as defined in [WIN2D6137]. The Satisfied User Criterion (SUC) is defined as an average active session throughput of 2Mbps or higher needs to be guaranteed for 95 percentile of users in downlink and an average active session throughput of 1.3Mbps or higher needs to be guaranteed for 95 percentile of users in the uplink.

The performance of baseline scenarios serves for comparison purpose of different simulators. Performance improvement due to relaying is quite obvious with respect to BS only deployment. The reference design achieves these improvements. In contrast to the baseline design it describes technology options that optimize the performance of relay based deployment for the different concept group scenarios.

The main motivation to deploy RNs is to decrease the overall network cost while maintaining a required service level. We have extended the methodology based on iso-performance curves illustrated in [WIN2D352] for single direction (or equivalently single service) to include both uplink and downlink (or equivalently multiple services). We illustrate that the reference relay based deployments are more cost efficient than BS only deployments for both the base urban coverage and the metropolitan area concept group scenario.

The refinement of the WINNER relaying concept will be performed combining contributions from all previous deliverables, both in phase I and II of the project, and will be delivered in a separate document at the end of the project.

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1 Introduction

Deliverable D3.5.3 is the final deliverable of T5 itself and the third in a row of three deliverables that describe and assess the WINNER relaying concept

Relaying technologies have been studied within WINNER since its beginning with the intention to create a low cost broadband network deployment. A fact which resulted in the objective to design an efficient relaying concept which is able to support the envisaged broadband radio coverage on the one hand and allows for cost efficient relay nodes on the other hand. The second major objective of the WINNER relaying group is to assess and proof the increased traffic performance as well as the cost advantage of the relay based WINNER system.

In the past two deliverables the relaying concept embedding the WINNER relay into the overall WINNER concept and protocol framework has been described to a sufficient level of detail. The protocol work is spread over all layers affected by the envisaged decode and forward relaying concept, namely the MAC RLC and RRC layer. (The reader interested in the details of the relaying concept is referred to D3.5.2 and D3.5.1 for further details.) It should also be mentioned that the WINNER relaying group since its beginning focussed on both single path and cooperative relaying, i.e. relaying which connects the User Terminals (UT) via one multi- or single -hop route (path) to the BS or by multiple routes (paths), whereby the cooperative relaying is seen as add on technology to boost the capacity in certain regions, where multiple radio access points have overlapping coverage area. Further baseline assumptions for the assessment of the relay based WINNER system have been developed for all three Concept Groups (CG) in D3.5.1, as well as a methodology to compare different deployments under economical aspects

Based on the developed relaying concept, the baseline assumption and the comparison methodology this deliverable is now providing a detailed assessment of different WINNER relaying technologies. The assessment is done in three ways and therefore structured in three different chapters.

Firstly the chapter following this introduction provides an assessment under consideration of the baseline assumptions, which will ensure the comparability of the simulation results rather than showing the real performance of the WINNER relaying concept. Thereby all three CGs are taken into consideration.

Chapter 3 provides an assessment of the WINNER relaying technologies in terms of traffic performance. The assessment is based on the baseline scenarios for the different CGs. Thereby results for different RRM schemes in terms of resource partitioning are shown as well as for the centralized scheduling scheme ProSched and for multicast broadcast (MCBC) services. In all cases the relay based system have proven to be advantageous compared to single hop deployments.

In Chapter 4 it is shown that the increase of traffic performance demonstrated in chapter 3 can also be transferred into an economic benefit in terms of a decrease in deployment cost while maintaining a certain level of system performance. The results of the const analysis have been achieved by stochastic simulation, as well as ray tracing tools considering a real world environment.

Finally the deliverable is concluded by Chapter 5 giving an outlook on the final work of the relaying group towards CG and system concept deliverables.

2 Baseline relay deployment scenarios

2.1 Introduction

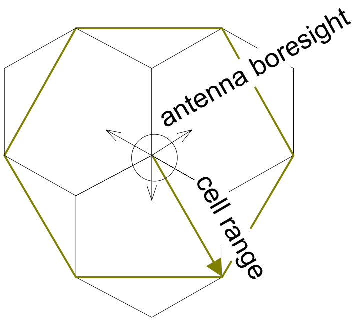
In this chapter we present and argue the baseline deployment scenarios for all three concept groups based on the available simulation results for different deployment options. The analyses and simulation campaigns shown in this chapter are based on the relay deployments and the baseline assumptions outlined in [WIN2D6137] in order to guarantee comparable results. These deployments pertain to the baseline scenarios only. The best deployment and relaying concepts for the reference design are likely to differ depending on the specific requirements. Results shown in D3.5.2 have proven that especially the baseline resource partitioning is far from optimum.

2.2 Wide area

The wide-area scenario aims at providing ubiquitous coverage in different propagation conditions resulting in rather large cells, having a radius up to some kms. Base stations are consequently expected to provide high power outputs and to be deployed above-rooftop, possibly requiring additional masts for their installation. This implies that the site selection and rental costs will probably be dominant with respect to other ones, e.g. the backhaul infrastructure.

The use of relaying in this scenario could help in reducing the infrastructure costs while maintaining the same level of service. For this reason, it is important that relay nodes have significantly lower deployment costs than base stations. They should be smaller in size, provide lower power outputs and below-rooftop deployment, possibly on pre-existing lamp posts.

In the currently assumed scenario, i.e. the base coverage urban, no specific topographical details are taken into account, and the cells form a regular grid with hexagonal layout. The inter-site distance (ISD) is specified as 1000 meters and the relay nodes are placed along the antenna boresight of each sector and at a fixed distance of 440 m (2/3 of cell radius) from the BS. An example of multi-cell deployment is depicted in Figure 2-1, while Figure 2-2 shows the deployment of relay nodes.



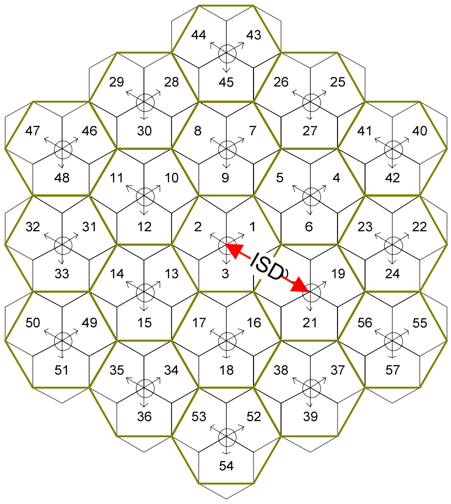


Figure 2-1 Sketch of base coverage urban cell layout

The selected duplex mode is FDD. Each base station has a maximum transmit power of 46 dBm (~40 W) per sector, and each of its 3 sectors is equipped with 4-antenna linear array. Relay nodes, on the other hand, have a transmit power of 37 dBm (5 W), and use a single omni-directional antenna in the baseline case. These assumptions could, however, change if the use of multiple antennas at the relay nodes proved to be advantageous.

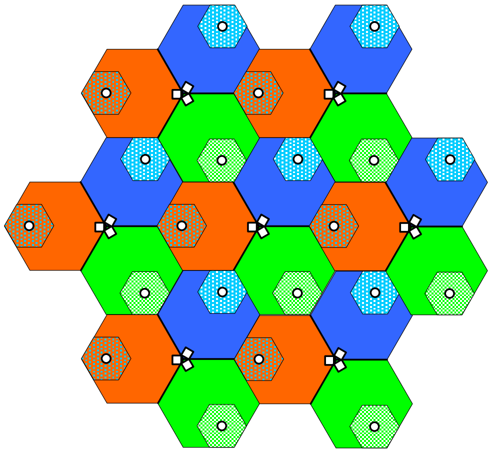


Figure 2-2 : Base coverage urban cell layout with relay nodes

In the following section 2.2.1 performance of relay based deployment in wide area is presented assuming the fixed resource partitioning proposed in [WIN2D6137]. On the contrary, in section 2.2.2 the fixed resource partitioning differs since it is derived based on the requirements of the BS-UT and RN-UT access links.

2.2.1 Performance evaluation of fixed resource partitioning

In Table 2-1 the parameters used in the simulations of the baseline deployment in wide area test case are illustrated. Results are obtained considering only the cell in the centre and 18 cells around, the C2 NLOS channel model was used for BS-RN links and B1 NLOS for RN-UT links. We have assumed an ideal approach for packet retransmissions due to errors: if a packet is received by the destination with errors, it will be en-queued in the source. This assumption consists of having an ideal feedback that is not affected by transmission errors. We have assumed larger packet size segmented into segments of 1200 bytes. Users are considered to be fixed in position.

Table 2-1: Simulation parameters.

Parameter	**Value**	**Comments**
Carrier frequency	3.95 GHz DL 3.7 GHz UL	
Channel bandwidth	2x50 MHz	
Number of cells	19	Cellular hexagonal layout
Inter-site deployment distance	1 Km	
BS – RN distance	444 m	
Spatial processing	BS-UTs: GoB	
BS number of antenna per sector	4	
RN number of antenna	1	
UT number of antenna	2	
BS transmission power	46 dBm	
RN transmission power	37 dBm	
UT transmission power	24 dBm	
Retransmissions (ARQ, HARQ)	Yes	Ideal: if a packet is received by destination with errors it is en-queued in the source.
Segmentation and Reassembly	Yes	
Link adaptation	Yes	

Mobility	No	No Handover but initial cell selection is implemented
Resource scheduling	Round Robin (RR)	
Resource partitioning	Fixed	Two approaches: Baseline Fixed Partitioning (BFP) and the Connection based Scheduling-Fixed Partitioning (CbS-FP)
Selection of best RAP	Signal strength	
Traffic model	Full buffer	

In Figure 2-3 we show the spectral efficiency versus number of users for the BS only deployment and the BS+RNs deployment using fixed resource partitioning. Two fixed resource partitioning have been considered: the Baseline Fixed Partitioning (BFP) as proposed in [WIN2D6137], as well as the Connection based Scheduling (CbS), which is also used for deriving the Fixed Partitioning (CbS-FP). The CbS approach has been already illustrated in [WIN2D351][ReCoCa+07] and consists of a dynamic approach. However in this context it has only been applied to obtain a fixed partitioning which is more appropriate than the one proposed in [WIN2D6137] and here referred to as BFS. The resource scheduling is Round Robin (RR).

The spectral efficiency decreases with an increasing number of users due to the overhead introduced by user plane packet processing, which increases with the number of users. As expected, the relaying solution has the potentiality to outperform the BS only deployment, however if appropriate protocol functions are not employed the possible gain can be lost. In particular in section 3.2.2 we show how a flexible radio resource partitioning can increase the performance of the relaying solution in the wide area test case.

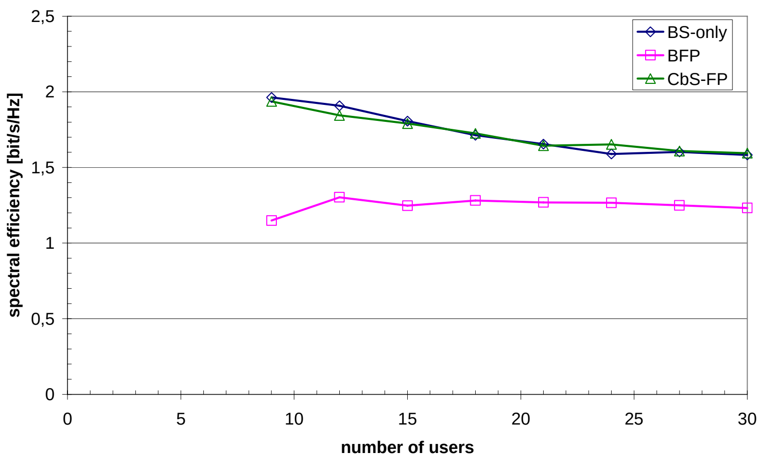


Figure 2-3: Spectral efficiency versus number of users for BS only deployment and BS+RNs deployment using fixed resource portioning. The Connection based Scheduling (CbS) is used to derive the Fixed Partitioning (CbS-FP). The Baseline Fixed Partitioning (BFP) is also reported according to [WIN2D6137].

2.2.2 Performance of the baseline scenario using static resource partitioning

The baseline deployment of [WIN2D6137] is investigated with and without relaying using static system-level simulations that model the long-term average SINR distributions considering path loss, shadowing, beam patterns, spatial processing, and interference. The baseline grid-of-beams scheme is used at the BS and MRC at the UT. Throughput calculation is based on a SINR-to-throughput mapping using a modified Shannon approximation considering Chase combining and the limitation due to the maximum modulation and coding scheme, as depicted in Figure 2-4. It has been shown [Ha07] that such a simulation approach is rather a good approximation of the results for dynamic system-level simulations with Round Robin scheduling and full buffer traffic.

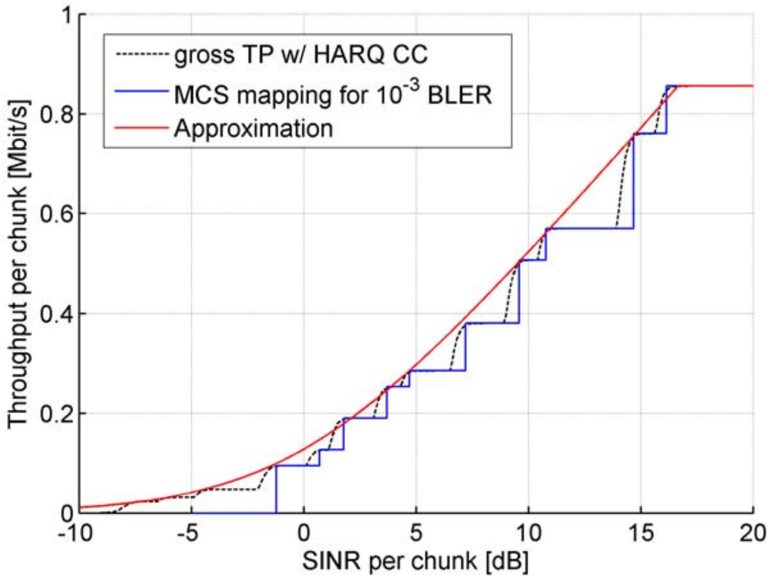


Figure 2-4: Throughput Mapping based on a modified Shannon curve considering HARQ retransmission and limitations due to maximum MCS

A fixed resource partitioning is derived based on the requirements to have equal user throughput in the areas covered by the base station and relay node and ensuring that the throughput of the BS-RN link (TP_{RL}) is greater or equal than the aggregation of the RN-to-user links (TP_{RN}). For identical services and uniform user distribution the former requirement leads to the constraint that the aggregate throughput at the RN and BS are proportional to the served area. Based on these assumptions the average number of chunks used at the RN K_{RN} can be expressed by:

$$K_{RN} = \frac{\alpha\left(K - K_{RL}\right)\cdot TP_{BS}^{ch}}{TP_{RN}^{ch} + \alpha TP_{BS}^{ch}}, \tag{2.1}$$

where K is the total number of chunks, K_{RL} is the number of chunks used in the relay link between the BS and RN, and TP_{BS}^{ch} and TP_{RN}^{ch} are the average throughputs per chunk at the BS and RN, respectively. α is the quotient between the number of users served by the RN and the BS. Note, that an iterative solution is required, since chunk throughput depends on the chunk power (max. Tx power is distributed equally between chunks), i.e. the number of chunks K used at a RAP which itself influences also the quotient of the served users, i.e. α. Evaluation of the relay link have shown that under the current baseline design the highest MCS can be used there. Using (2.1), the SINR-to-throughput mapping depicted in Figure 2-4, and the 2-hop capacity metric

$$\frac{1}{TP_{2hop}^{ch}} = \frac{1}{TP_{RL}^{ch}} + \frac{1}{TP_{RN}^{ch}}, \tag{2.2}$$

the SINR threshold can be derived to determine whether initial cell selection should connect to the RN or to the BS, see blue curve in Figure 2-5. For low SINR user links the resources occupied by the relay link are negligible and simply connection to the RAP with highest SINR can be used. In the range of very high SINRs user links and relay links can use the maximum modulation and coding scheme. Then the BS connection needs only to provide half of the throughput, since the relay connection consumes twice the resources due to the in-band relay link. Therefore for SINR of the BS link greater than 9 dB the BS connection is always favourable.

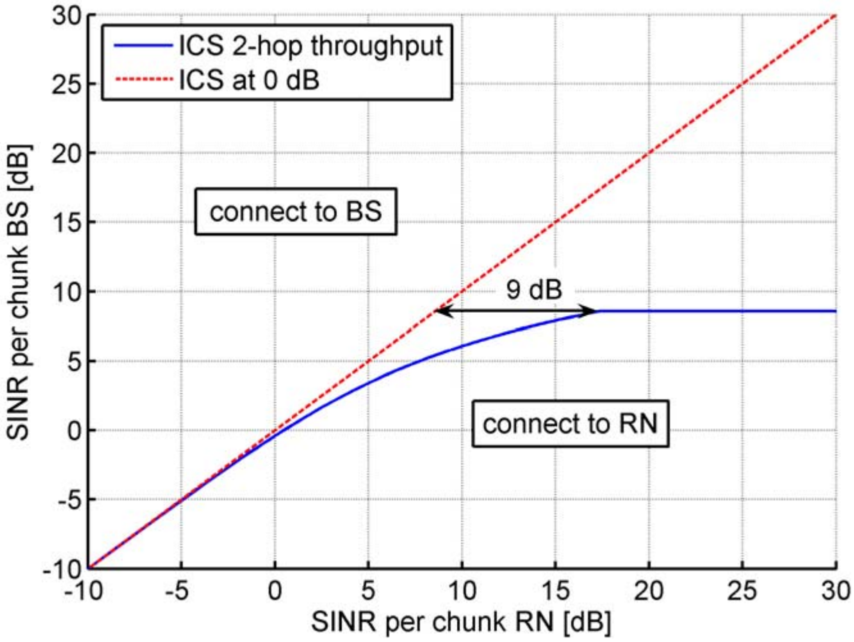


Figure 2-5: SINR threshold for initial cell selection

Simulation assumptions follow the base coverage urban case in [WIN2D6137], and are identical to those described in Table 2-1 unless otherwise indicated in Table 2-2. For a particular shadowing situation, a comparison between BS-only and relay-enhanced deployment is shown in Figure 2-6. It can be seen that with the current parameterisation of the relay nodes focussing on small, low-cost devices the improvement is limited to the close environment of the RN and multiple RNs would be required to cover all the shadowed areas in one cell. Since additionally the location of the RN is fixed and not deployed at e.g. areas shadowed from the BS, the following results can be considered lower bounds on performance.

Table 2-2: Simulation parameters

Parameter	**Value**	**Comments**
Spatial processing	BS-UTs: Grid of Beam (GoB) for unicast and STBC (Alamouti) for multicast	MRC at UT
BS antenna element gain	14 dBi	
RN antenna pattern	as in D6.13.7	
BS height	25 m	
RN antenna element gain	9 dBi	
RN antenna pattern	omni	
RN receiver noise figure	5 dB	
RN height	5 m	
UT antenna element gain	0 dBi	
UT antenna pattern	omni	
UT receiver noise figure	7 dB	
UT height	1.5 m	

Retransmissions (ARQ, HARQ)	Yes	for SINR lower than the lowest MCS an appropriate number of retransmissions is calculated (assuming Chase Combining) an throughput is reduced accordingly
Segmentation and Reassembly	No	
Link adaptation	Ideal	
Mobility	No	No Handover, No user movement, long-term average
Resource scheduling	Round Robin (RR)	
Resource partitioning	Fixed	Baseline Fixed Partitioning (BFP) , with some basic optimization; required resources at BS-RN link calculated based on link budget and extracted from the resource pool
Selection of best RAP	Signal strength	As described in the text: RN needs to be 9 dB better than BS, 0 dB threshold between BS or RN

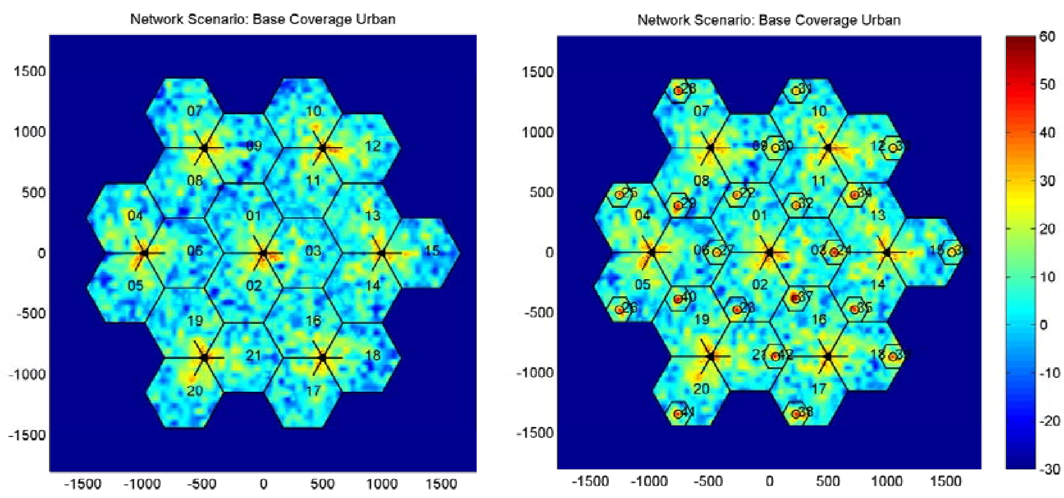


Figure 2-6: Comparison of long-term average SINR including shadowing

The corresponding SINR distributions are given in Figure 2-7 for the BS-only base coverage urban test scenario (BCU) and for relay-enhance cells (REC). The black curves assume outdoor UTs, whereas the red curves assume indoor users and include additionally 20 dB wall penetration loss. The improvement due to relaying is obvious and further improvement is expected using more than one relay per cell. Furthermore we observe that indoor coverage is a challenge. Simulations have shown that noise limitation starts at around 10 dB penetration loss already. For the BCU indoor case the 5%-ile is decreased by 8 dB to -5 dB and already two retransmissions of the lowest MCS would be required. Relaying allows to improve the 5%-ile by 3 dB and cell edge throughput is increased by 50% already in this baseline case. Therefore it can be concluded that relaying is very useful to improve indoor coverage in particular at the cell edges. The average cell throughput is improved by 10% in this case, see Table 2-3.

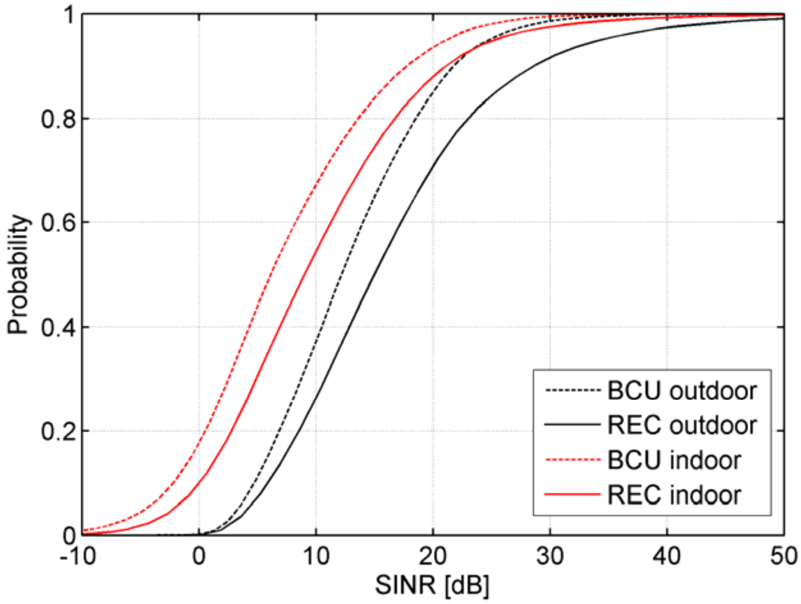


Figure 2-7: Impact of penetration loss for indoor coverage by outdoor radio access points

Table 2-3: Performance Comparison for baseline modulation and coding scheme (max. 64-QAM, *R* = 0.75)

Scenario	Penetr. loss [dB]	5 % SINR [dB]	Cell TP [Mbps]	Normalized Cell TP [b/s/Hz/cell]
BCU	0	3	96	1.9
REC	0	4	94	1.9
BCU	20	-5	63	1.3
REC	20	-2	68	1.4

From Figure 2-7 one can see that a relatively high SINR case exist, where the maximum modulation and coding of the baseline MCS (64-QAM, R = 0.75) limits throughput (cf. Figure 2-4). Therefore the simulations were repeated using the reference MCS including up to 256-QAM, R = 0.92. Table 2-4 shows that in particular the REC cases benefit from this improvement and outperform the BS-only cases by 6% in the outdoor case and by 16% for indoor users.

Table 2-4: Performance Comparison for extended modulation and coding scheme (max. 256-QAM, *R* = 0.92)

Scenario	Penetr. loss [dB]	5 % SINR [dB]	Cell TP [Mbps]	Normalized Cell TP [b/s/Hz/cell]
BCU	0	3	108	2.2
REC	0	4	115	2.3
BCU	20	-5	68	1.4
REC	20	-2	79	1.6

2.3 Metropolitan area

In the microcellular test case, a two-dimensional regular grid of streets and buildings is considered, the so-called Manhattan grid. The BSs are placed in the middle of the streets, in the midpoint between two cross-roads. Two sectors are formed with array bore-sight along the street direction, but with 180° coverage each. For these baseline simulations we used single antenna BS and RNs. However, the BS can be equipped with up to 4 cross polarized antennas per sector, with an inter element spacing of 0.5λ [WIN2D6137].

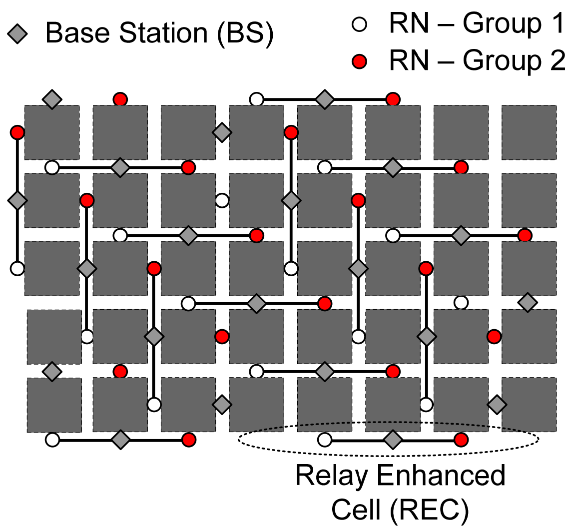


Figure 2-8: Sketch of microcellular cell layout with relay nodes

RNs are equipped with omni-directional antennas and they are divided into two groups. The available bandwidth is equally divided between these two groups. BSs use the whole bandwidth for their transmissions. The simulations are performed for a static resource partitioning, whereas the BS transmits to and receives from both the UT and the RN in two out of three frames and the RNs serve its UTs every third frame.

In the performance evaluation of baseline deployment we use the B1 LOS path-loss and channel model for nodes in the same street and B1 NLOS for nodes in different streets [WIN2D111]. Further, we utilize a two stage scheduling approach similar to the approach described in [PPM+07]. A time domain scheduler guarantees fairness between the users. It selects the 6 users with the lowest average throughput in the last 50ms. The frequency domain scheduler uses the proportional fair criteria to improve the spectral efficiency. The user throughput statistics have been collected every 400ms. The results are collected from 4 cells in the centre and 21 cells around the centre cells are fully modelled including scheduling and user traffic. The rest of the 97 cells are modelled as interfering cells, i. e. the user traffic and the scheduling are not modelled. The user density is kept constant in all the simulations and the user terminals move only on streets and in areas served by the active cells. The active cells cover about 0.6sqkm and the monitored cells about 0.12sqkm. Selected simulation parameters are presented in Table 2-5.

Table 2-5: Selected simulation parameters for baseline simulations.

BS Tx power	30dBm	MCS set for user data	BPSK 1/2, QPSK 1/2, 16 QAM ½, 2/3, 3/4, 64 QAM ½, 2/3, 3/4
RN Tx power	30dBm	MCS set for control data	QPSK & BPSK 1/2 for BCH and RACH
BS antenna	directional with 70deg beamwidth	ARQ	Yes (No HARQ)
BS antenna gain	14dBi	Time Domain Scheduling	Equal Throughput
BS No. sectors	2	Frequency Domain Schedul-	Proportional fair

		ing	
RN antenna towards BS	directional 70deg beamwidth	Time Domain Scheduling	Round Robin/Equal Throughput
RN antenna towards UT	omni-directional	Initial RAP Selection	RAP with highest signal strength
RN antenna gain towards BS	14dBi	Cell reselection handover	Signal strength with hysteresis
RN antenna gain towards UT	7dBi	Handover	Hard handover
RN No. sectors	1	Handover margin	3dB
Carrier Frequency	3.95GHz	Network synchronization	Fully Synchronized
Signal Bandwidth	100MHz	Call arrival process	Poisson arrivals
Duplexing method	TDD	User density	1464 users per sqkm
Manhattan Grid Dimension	11x11 blocks	Simulation Steps	3Mio
Building Block Size	200m	Traffic model	full buffer
Street Width	30m	User speed	3km/h
Link Adaptation	Yes		

In the baseline simulations we compare the user throughput CDF of the relay deployment illustrated in Figure 2-8 and the same scenario without RNs, denoted as BS only scenario. In the BS only scenario the BS can serve its UTs all the time. As can be seen from the user throughput CDF in Figure 2-9 the baseline relaying scheme performs much worse than the BS only deployment, e.g. the median user throughput is only one third. Further, the throughput of the UTs served by the RNs is much smaller than the throughput of UTs served by the BS, which indicates a problem in the resource partitioning. The baseline resource partitioning has been developed for RNs with a significantly smaller coverage area than a BS. However, in the metropolitan area concept group scenario the RNs have about the same or even larger coverage area than the BS. Thus, the resource partitioning has to be adapted accordingly. As expected, the results improve significantly for better resource partitioning schemes, which is illustrated by the results in Section 3.3. Thus, we can conclude that the baseline relay deployment with static resource partitioning and too many restrictions on the resource usage is not performing well.

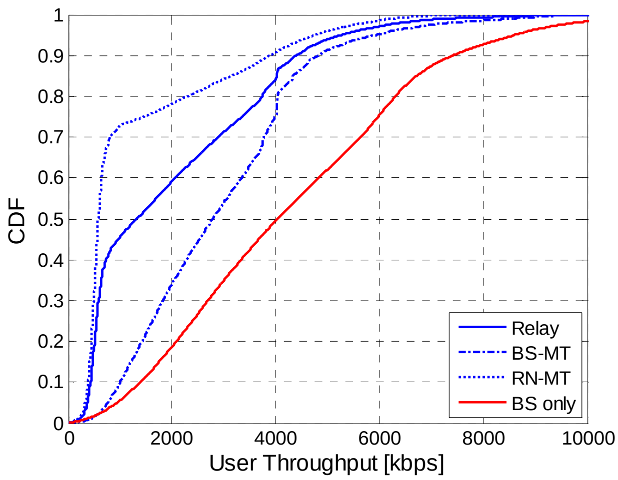


Figure 2-9: User throughput CDF comparison of the baseline relay deployment with static resource partitioning and the BS only deployment. In addition to the overall user throughput CDF of all users in the REC, it also shows separately the user throughput CDF of UT served by the BS and the RN. The static resource partitioning with high restrictions degrades the performance of the relay deployment.

Figure 2-10 compares the SINR CDF of the downlink received packets for the baseline relay deployment and the same deployment without RNs. The SINR of the packets is clearly higher for the relay deployment, e.g. the median SINR is 10dB higher and the difference increases up to 18dB for the higher parts of the CDF. Nevertheless, the SINR distribution also indicates that the performance of the relay deployment could be increased by a less restrictive resource partitioning to allow more parallel transmissions while decreasing the SINR to a tolerable value.

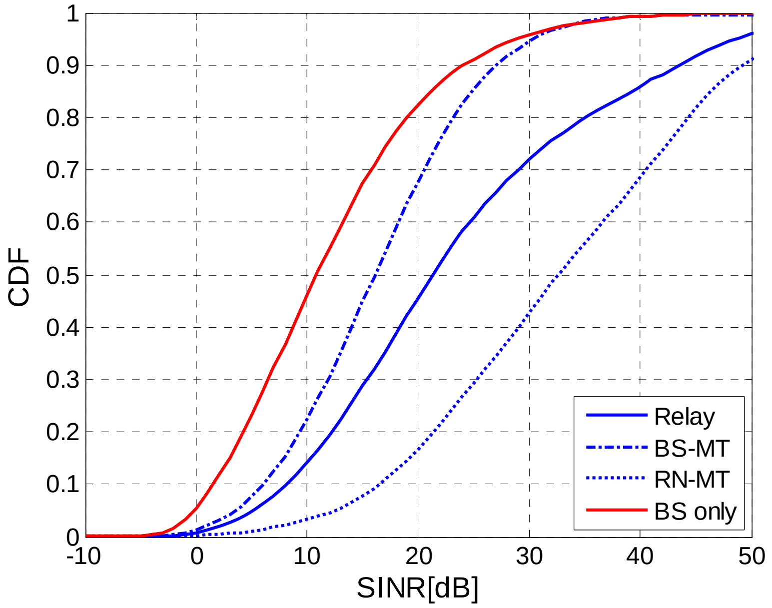


Figure 2-10: SINR CDF comparison of the baseline relay deployment with static resource partitioning and the BS only deployment. In addition to the overall SINR CDF for all packets received in the REC, it also shows separately the CDF for packets received by UTs served by the BS and the RN.

2.4 Local area

The local area scenario is defined as an isolated hot-spot-like area located indoors, where user density can be high and typically users are stationary. Such a scenario is characterised by high shadowing and considerable signal attenuation due to the existence of rooms separated by walls. As a result of its isolated characteristic it also features low interference from other cells when compared to the outdoor cases.

The scenario, as depicted in Figure 2-11 consists of one floor (3 m high) in a building and contains two corridors (5 m x 100 m) and 40 rooms (10 m x 10 m). In the baseline relay deployment four relay nodes (green ones) are coordinated by the base station (red node) located in the centre. RNs are placed in the middle of the corridors, 25 m and 75 m away from the left side of the building, respectively. They are equipped with up to 2 antenna elements, whereas the base station may employ more antenna elements.

Figure 2-11: Deployment of RNs in LA scenario

The baseline scenario without relays [WIND6137] employs four antenna arrays instead. They are operated as remote radio heads and each of them contains 8 antennas. Each antenna array is rotated by 45° and they are placed at the same positions as the relay nodes in the baseline relay deployment. Some additional results on deploying distributed antennas in this scenario can be also found in [WIN2D341].

3 Reference design performance

3.1 Introduction

We have presented the performance of the baseline scenarios as defined in [WIN2D6137] in section 2. These scenarios have been defined as common comparison scenarios that should allow comparable results of different simulators. In contrast the reference design examples demonstrate technology options that improve the performance of relay based deployments compared to the baseline design.

In section 3.2 we present reference design examples for the WA CG scenario. In particular we illustrate how relay deployments can improve the SINR of multicast and broadcast transmissions. First results on dynamic resource allocation for RECs in [WIN2D352] indicate significant performance improvements compared to traditional sectorization and in section 3.2.2 extend this performance evaluation.

Further reference design examples for the MA CG scenario can be found in section 3.3. We study for example the impact on performance of the use of directive antennas at the RN and of resource partitioning scheme combined with soft-frequency reuse. Moreover, we present performance results of a simple multi-user scheduling approach for RECs with cooperation.

3.2 Wide area

3.2.1 Multicast / Broadcast transmission in relay-enhanced cells

Delivery of multimedia services is a key ingredient of WINNER. Many multimedia services, such as video streaming need to be received by many users which might also be distributed over a larger area. Therefore multicast and broadcast (MCBC) transmissions are required which establish such point-to-multipoint wireless connections.

In the multicast case the network has at least partial knowledge about the served users, whereas broadcasting is performed without any information about the recipients. These limitations severely restrict possibilities for link adaptation and spatial processing and therefore low link spectral efficiency is obtained. However, since the same radio resources are used to serve many users, system spectral efficiency can outperform those of point-to-point connections starting from a certain number of users in the MCBC group. We address this trade-off and estimate the average MCBC group size required to benefit from this effect.

3.2.1.1 Design of MCBC transmission

MCBC transmission is based on the non-frequency adaptive transmission mode which uses B-EFDMA to obtain frequency diversity. In the base coverage urban test scenario a fixed grid of beams is used for unicast transmission. For broadcast transmission it is not reasonable to use beamforming because coverage has to be provided for all users in the cell at the same time. Instead diversity techniques like the Alamouti space time block code should be used. A fixed number of retransmissions and Chase combining is used to enable MCBC service for low SINR users. To be compatible with half-duplex relay nodes either one or three retransmissions must be used as depicted in Figure 3-1.

We focus our investigations on the broadcast case, where no CQI is available. Therefore coding and modulation needs to be adapted to ensure proper reception in most of the coverage area. We assume that 95% of the area needs to be served, i.e. the modulation and coding scheme is chosen, which corresponds to the 5%-ile of the long-term average SINR (after Chase Combining) observed in the WA baseline scenario with one relay per cell .

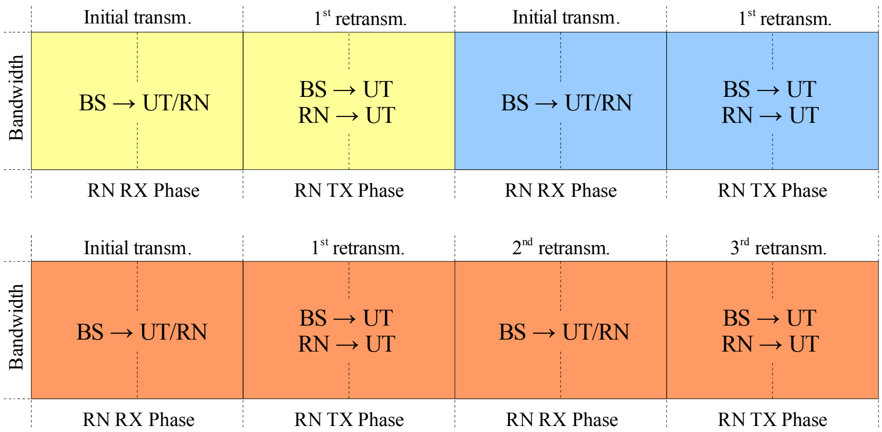


Figure 3-1: Fixed retransmission scheme for MCBC in relay-enhanced cells

Link adaptation to the low SINR (e.g. cell edge) users results in poor link efficiency. Exploiting macro diversity offered by local single frequency networks (SFN) is a technique to improve cell edge SINR. In SFNs data are sent by different radio access points on the same resources and combined at the receiver.

Achieving such co-ordinated transmission (and the required synchronisation) between the radio access points (i.e. the BS and relays) of one site is straightforward since they are controlled by one BS. SFNs extending over several sites offer potentially additional gain, however, at the expense of co-ordination overhead and synchronisation requirements between different BSs.

Unless otherwise indicated in this section, the simulation assumptions are as described in Section 2.2.2. Figure 3-2 shows the SINR distributions with and without relaying and different configurations of the SFN assuming outdoor users. At the 5%-ile a SFN per site with relay-enhanced cells already improves the SINR by 2 dB, whereas a 3-site SFN provides additional 1.8 dB gain. It is important to note, that for a single-site SFN no macro diversity gain is obtained at low SINRs if relaying is not used. For BS-only deployments notable gains are only seen for a SFN extending over three sites, which means only if inter-BS co-ordination and synchronization is ensured. The combination of relaying and SFN, however, provides already significant gain and the simple single-site SFN in REC outperforms significantly the more complex 3-site SFN in a deployment without relays. The combination of relaying and SFN is therefore an interesting option to improve link efficiency of MCBC transmissions.

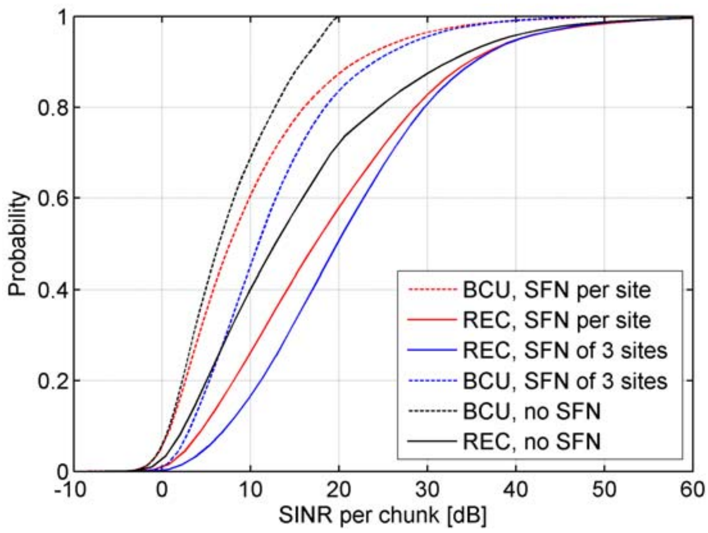


Figure 3-2: Comparison of long-term SINR distribution for the base coverage urban (BCU) deployment without relays, for relay-enhanced cells (REC) and using different sizes of the local single-frequency network (SFN)

Table 3-1 compares the resulting link efficiencies for point-to-point (p-t-p) transmission (using grid-of-beams at the BS) and point-to-multipoint (p-t-m) transmission using the Alamouti and different SFN variants. For the single-site SFN, relaying allows to improve link efficiency by 45% for outdoor users and by

100% for indoor users. Extending the SFN over three sites improves link efficiencies additionally between 15% and 30%.

Table 3-1: Link efficiencies of point-to-point and point-to-multipoint links in different deployments

		p-t-p	p-t-m		
			No SFN	SFN 1 site	SFN 3 sites
Outdoor	BCU	1.9	0.32	0.33	0.43
	REC	1.9	0.37	0.48	0.60
Indoor	BCU	1.3	0.03	0.04	0.05
	REC	1.4	0.05	0.08	0.12

The link efficiencies can be used to estimate the required number of users in the MCBC transmission until equal or better system efficiency is achieved. Table 3-2 shows that relaying allows to use MCBC efficiently already at lower MCBC group sizes, especially if indoor users need to be served.

Table 3-2: Required MCBC group size to outperform p-t-p performance

	SFN 3 sites		SFN 1 site	
	BCU	REC	BCU	REC
Outdoor	5	4	6	5
Indoor	26	12	33	18

Based on the WINNER channel models and propagation delays between RAPs the impact of synchronisation errors has been investigated. Due to the involved differences in path loss, delay spread, and relative propagation delay have shown minor impact. Also the design is robust with respect to Doppler spread. On the other hand time and frequency sychronisation errors might occur between different sites (perfect synchronisation of all RAP of one site, as well as of the UTs is assumed). Figure 3-3 shows the gain at the 5%-ile of the SINR CDFs for a SFN in relay-enhanced cells of three sites as compared to a deployment without SFN. The subcarrier spacing is 39 kHz, symbol duration is 28.8 µs. The residual gain of around 1.8 dB is the gain that remains due to the SFN per site. From this plot the requirements for inter-site synchronisation can be extracted for a given target SINR gain at the 5%-ile.

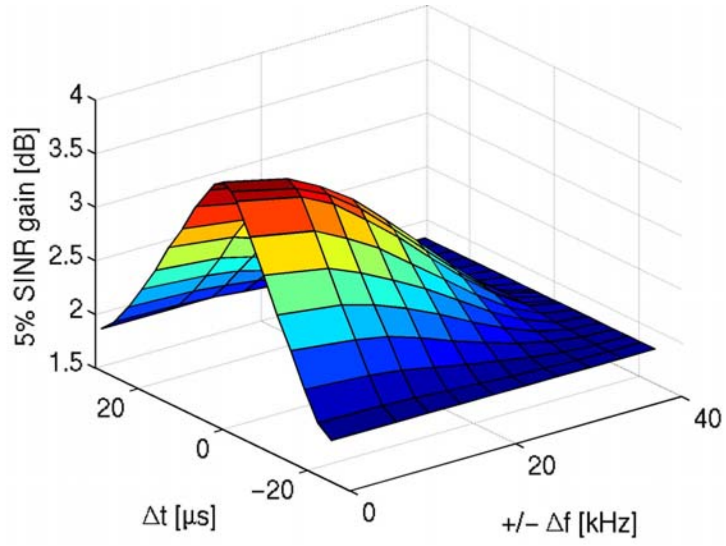


Figure 3-3: Gain at the 5%-ile of the SINR CDF for a SFN of three sites of relay-enhanced cells as a function of time and frequency synchronization errors between the sites

3.2.2 Resource partitioning based on dynamic approach

In this section we provide more insight of performance evaluation for relay based deployment in wide area test case of the dynamic resource partitioning scheme previously proposed in [WIN2D351][ReCoCa+07] and named Connection based Scheduling (CbS). Further improvements are expected also adopting enhanced SDMA concepts, as already presented in [WIND352] section B.1.

In Table 3-3 parameters used in the simulations are illustrated. They follow the assumptions proposed in [WIN2D6137] and used in section 2.2.1 for baseline scenario evaluation, but differ in the resource partitioning approach which now is dynamic.

Table 3-3: Simulation parameters.

Parameter	**Value**	**Comments**
Carrier frequency	3.95 GHz DL 3.7 GHz UL	
Channel bandwidth	2x50 MHz	
Number of cells	19	Cellular hexagonal layout
Inter-site deployment distance	1 Km	
BS – RN distance	444 m	
Spatial processing	BS-UTs: GoB	
BS number of sectors	3	
BS number of antenna per sector	4	
RN number of antenna	1	
UT number of antenna	2	
BS transmission power	46 dBm	
RN transmission power	37 dBm	
UT transmission power	24 dBm	
Traffic model	Full buffer	
Retransmissions (ARQ, HARQ)	Yes	Ideal
Segmentation and Reassembly	Yes	

Link adaptation	Yes	
Mobility	No	No Handover but initial cell selection is implemented
Resource scheduling	Round Robin (RR)	
Resource partitioning	Dynamic	Connection based Scheduling (CbS) already illustrated in [WIN2D351] and [ReCoCa+07].
Selection of best RAP	Signal strength	

The following results show potentialities of employing a dynamic resource partitioning scheme. The Connection based Scheduling (CbS) is well suited for this scope [WIN2D351][ReCoCa+07]. In Figure 3-4 we show the spectral efficiency versus number of users for the BS only and the BS+RNs deployments using dynamic partitioning based on CbS (CbS-DP). Round Robin has been adopted as resource scheduling. The Baseline Fixed Partitioning, as proposed in [WIN2D6137] is also plotted for comparison purpose.

It is clearly shown that the relaying solution outperforms the BS only deployment; further improvements are expected adopting enhanced SDMA concepts, as already shown in [WIND352] section B.1, and assuming more than one relay per sector.

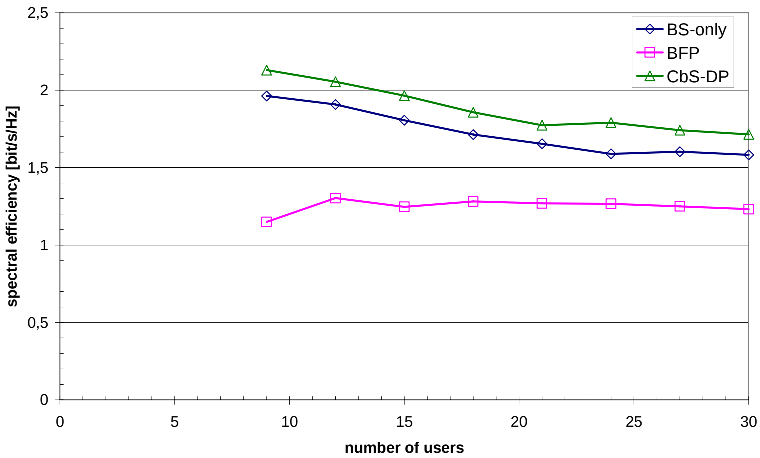


Figure 3-4: Spectral efficiency versus number of users for BS only and BS+RNs deployments using dynamic resource partitioning. The Connection based Scheduling (CbS) has been adopted in order to show potentialities of a dynamic partitioning (CbS-DP). The Baseline Fixed Partitioning (BFP) is also shown for comparison purpose.

3.2.3 Static Load-based resource Partitioning

Load-based resource partitioning is intended to provide a cost-efficient yet flexible solution to partition resources in REC-based deployments. Cost-efficiency is targeted through low hardware requirements while the possibility to frequently re-arrange the grouping offers the required flexibility. The concept applies a fragmentation of the resources in the frequency domain. The resources are assigned to so-called groups of RAPs, where - in the extreme case - each RAP node belongs to a distinct group while - in the other extreme - all RAPs could belong to one group. The groups are used by the partitioning algorithm for intracell frequency planning – RAPs belonging to the same group may reuse the same resources. In order to exploit the resources within a REC as efficiently as possible, the static resource partitioning can try to identify RAPs within the REC that are sufficiently well separated from each other to enable re-using the same resources. In the case of centralized resource partitioning, the groups may also be used for intercell frequency planning.

The optimal fragmentation of resources within the REC also highly depends on the distribution of the users, i.e. of the offered traffic within the REC. Therefore, the algorithm has to be able to take this distribution into account when assigning resources to the different groups of RAPs

The main interdependency with other functions is seen with forwarding - the partitioning has to take into account and/or influence, at which point in time a RN is acting like a BS / UT respectively.

The overall spectral efficiency of the relay based deployment highly benefits from a spatial reuse of the resources, not only between different relay subcells as outlined above but also on the relay link. It is therefore envisaged that the BS uses SDMA based on beam forming to feed the RNs. In addition a careful placement of the RNs with respect to the BS is considered and thus yields maximum spectral efficiency on the relay links.

3.2.3.1 Simulation Assumptions

The goal of the simulations is to provide an estimation of the performance of the WINNER protocol in Wide-Area mode under non-full buffer assumptions with SDMA group scheduling at the BS and bounded buffer-capacity at all nodes.

Table 3-4: Overview about investigated partitioning.

Scheme	Legend entry	Description
Single Hop (numRN = 0)	"None"	Full reuse, single hop, serves as comparison case.
Case 1 (numRN = 3)	- Not shown -	RNs only active in a part of a frame - *Results not shown because capacity distribution from the scheme did not fit scenario.*
Case 2 (numRN = 3)	"No Reuse"	Can be considered as the baseline case No intra-REC interference between RN subcells, all RNs active in the same frame and its resources are shared among them
Case 3 (numRN = 3)	"Alternating-Frames"	No intra-REC interference between RN subcells Frame 1: Relay Node 3 forwards, BS1 serves users and RN2 and RN4 Frame 2: RN2 and RN4 forward, BS1 serves RN3
Case 4 (numRN = 3)	"Full Reuse"	Full reuse i.e. higher intra-REC interference between RN subcells, but higher diversity Frame 1: BS 1 serves UTs and RNs Frame 2: RNs serve UTs, BS silent

Figure 3-5 and Table 3-4 present 4 exemplary outcomes of the above described Resource Partitioning Algorithm for different amounts of users present in the respective subcells of each RAP (visualized through the RNs' varying coverage areas). The number of users covered by the RNs increases from left to right. Consequently, the amount of resources partitioned for use by the RNs is correspondingly increased. The two cases also differ with respect to the timing of the relay nodes. In the Baseline Assumptions, per default all RNs act as BSs in the same frame of the super frame.[1]. Alternating operation of RNs as RAPs is proposed as illustrated in the third case of Figure 3-5. The concept further supports dedicating partitioned portions of the resources to a certain type of usage, i.e. Feeding RNs, Serving UTs or both. In the second frame, the group 1 resources are dedicated to feeding only. Thus no traffic of users on the first hop will be scheduled here.

Deployment and Traffic:

The target of the proposed static partitioning scheme is to provide a low-cost alternative with low hardware requirements put to the relay nodes. More complex hardware (i.e. Beamforming Antenna) is only used at the Base Station. The envisaged deployment is characterized by: (a) Single (Omni directional) Antenna Relay Nodes, (b) Single Transceiver Relay Nodes (Relaying in the Time Domain) (c) Smart Antenna Technology at the BS only, to keep RN equipment cost low.

The spatial grouping at the base station is performed according to a tree-based algorithm applying a DoA-heuristics as described in [HoElPaSc07]. An additional feature is that RNs and UTs are grouped into distinct groups to be able to fully exploit the good channel conditions on the relay link.

[1] However, in scenarios where (a) a large number of UTs will be served by RNs and not by the BS immediately and (b) no frequency reuse between RN subcells is desired it seems more beneficial to dedicate a higher number of resources to RNs

Traffic has been modelled according to a per-user poisson arrival process (neg. exp. Distributed packet inter-arrival times). All simulations were run with a fixed number of 44 Users per REC. Scaling of the overall traffic load per cell has been performed by scaling each user' share of the traffic. Example: At 50 Mbit/s cell load, each user has an individual offer of 50e3 / 44 = 1.136 MBit/s. At a fixed packet size of 128 byte, this corresponds to an average of 1110 packets per second and user.

User terminals within the area of a REC, are evenly distributed in circular areas around each RAP (see Figure 3-6). As an exemplary distribution, the 44 UTs in the cell were divided into 26 UTs immediately connected to the BS and 18 UTs connected via the 3 RNs (6 each). In the single-hop comparison case, all 44 Users were connected to the BS immediately.

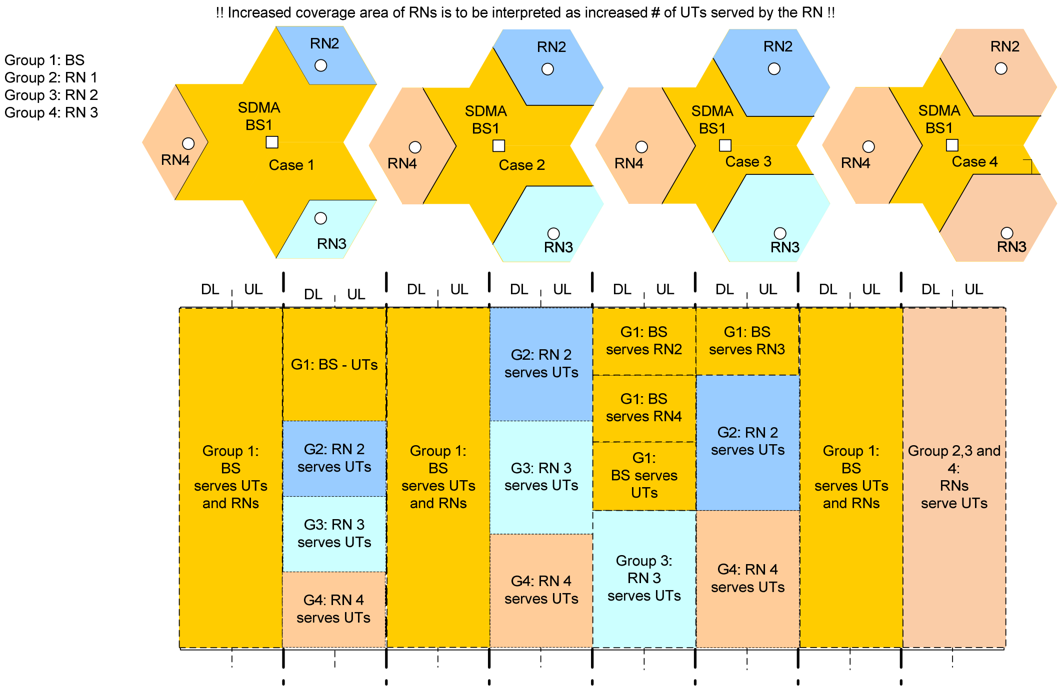


Figure 3-5: Different exemplary outcomes of the resource partitioning algorithms. Left: small share for Relay Links and first hop Access Links, right: bigger share for Relay- and first hop Access Links, full frequency reuse in all relay-subcells.

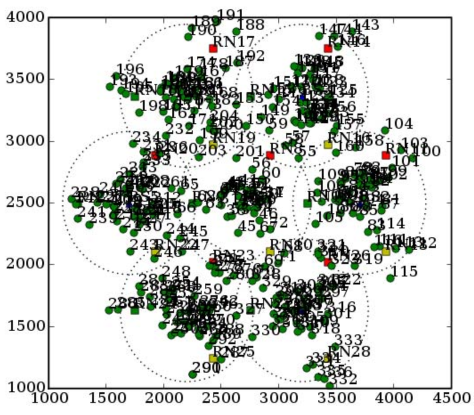


Figure 3-6: Multi-Cellular deployment with 44 UTs per REC in a wide-area setup (3 RN per BS).

Protocol Characteristics:

The available physical resources have been divided into Resource Allocation Units (RAUs) according to the proposal in [WIN2D6137] for non-frequency-adaptive transmission. This results in 18 parallel, interleaved subchannels, each of which comprising 64 subcarriers and spanning approximately 20 MHz (see below) and 3 OFDM symbols in the time domain. Consequently, A RAU provides 192 Symbols.

Base stations, Relay Nodes and user terminals apply a combined uplink power control and resource allocation scheme as presented in [WIN2D352]. DL scheduling is following an Exhaustive Round Robin strategy, scheduling spatial groups of users at the BS and individual users at the RNs.

In order to detect bottlenecks, all nodes in the simulation could drop packets when their buffer capacity was exceeded. BS and UT have "outgoing" buffers while the RN has a "forwarding" buffer.

Overhead taken into account is 1 block length (i.e. 3 OFDM Symbols) at the beginning of each frame for the out-band signalling of the resource allocation information (see Figure 3-7). In the uplink, additional overhead is taken into account since each user sends one Resource Request per frame to inform the RAP's scheduler about the fill level of their buffers (which resource scheduler in the RAP uses for UL scheduling).

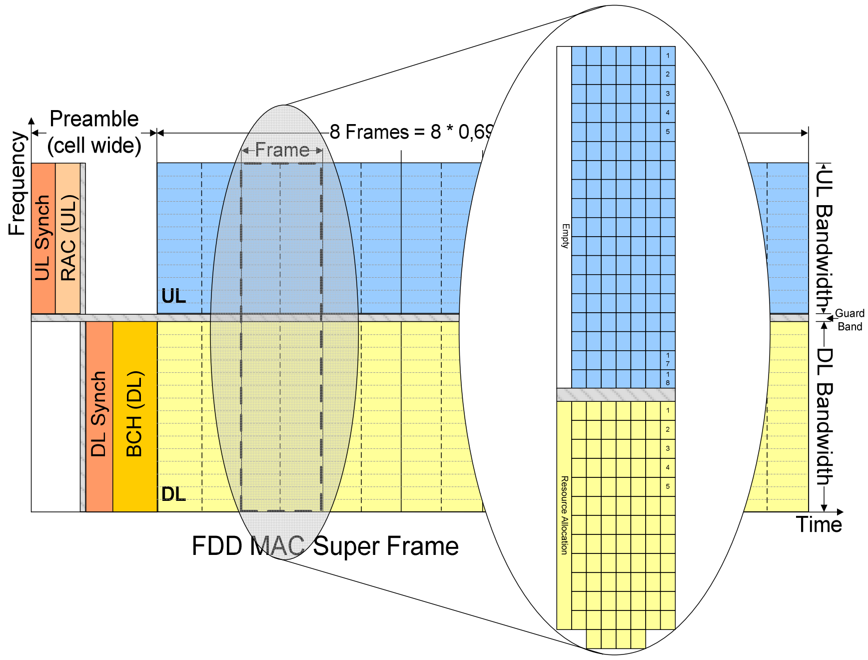


Figure 3-7: Resource Allocation Units and reserved signalling overhead (12.5%) in the FDD frame structure.

Link Adaptation in both UL and DL was performed based on long-term averages of received power and interference levels, taking into account the expected beam forming gains. A fixed code rate of ½ and no additional puncturing was assumed. The modulation was chosen according to the SINR prediction and switching thresholds were obtained from [WIN2D6137]. The Link-Level Mapping was performed according to LDPC coding curves from WINNERII task 2.

The applied propagation models in the simulations were chosen in view of the planned deployment of the RNs:

BS → RN: C1LOS (C2NLOS to RNs belonging to other BSs)

BS → UT: C2 NLOS

RN → UT: B1 LOS (RN to UTs in other subcells: B1 NLOS)

3.2.3.2 Simulation Results

The Simulation results compare the cases 2, 3 and 4 from Figure 3-5 with a single-hop case where all spectral resources are available for scheduling at the BS in all available frames. In the legends of the various figures, the different schemes are denoted as described in Table 3-4.

3.2.3.2.1 Downlink

Figure 3-8 shows the DL sustained REC throughput vs. the total offered DL traffic. The 3 relaying cases improve coverage as the performance at low traffic loads shows. In the high traffic load regime, case 3 seems to be not suitable under the given user distribution. Cases 2 and 4 perform equally well and allow a stable saturation cell throughput of about 80MBit/s.

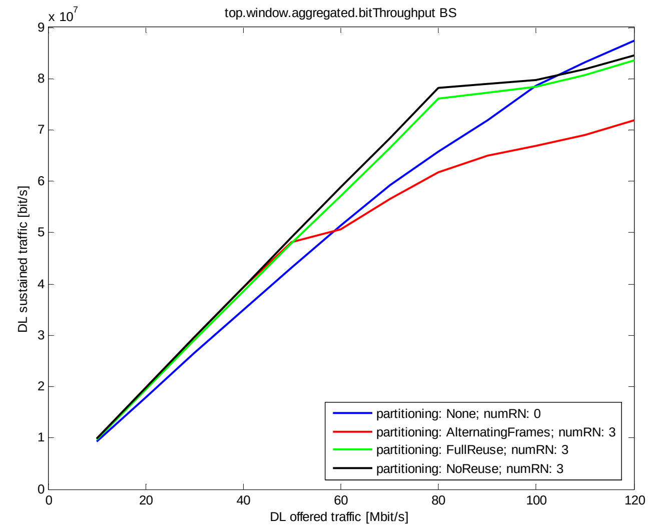


Figure 3-8: DL sustained traffic vs. offered traffic.

It can be observed from Figure 3-12 that the reason for the slightly lower Throughput of case 4 against case 2 lies in the worse conditions on the second hop. Figure 3-12 plots the successfully transmitted traffic rate on the second hop vs. the total transmitted amount of traffic. Owing to slightly higher interference in the "FullReuse" case, a small percentage of packets are lost on the second hop, but the general observation is that most traffic can be handled in both case 2 and case 4.

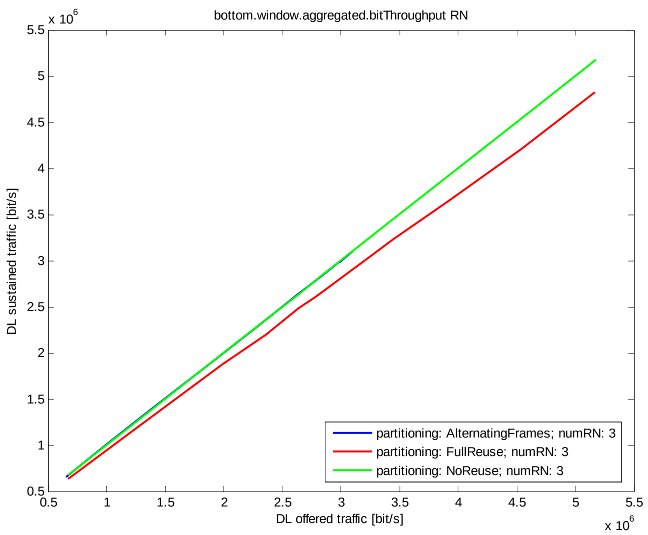


Figure 3-9: sustained DL RN-UT traffic vs. total outgoing RN-UT traffic.

In Figure 3-10 the cumulative distribution function (CDF) of the DL SINR received from the serving RAP as measured by the User Terminals is shown. It must be noted that 18 out of 44 Users (41%) are on 2-Hop connections, while the remaining 26 users (59%) are served by the base station immediately. The figure shows that in the single-hop case, more than 20% of all users encounter an SINR below 0 dB, which explains the outage already observed in Figure 3-8. Introducing relay nodes yields a 5dB gain of the median SINR while improving the 95th percentile by about 7dB in the worst of the compared partitionings. The partitioning with mutual protection of the RNs resources even yields an additional 5dB at the 95th percentile.

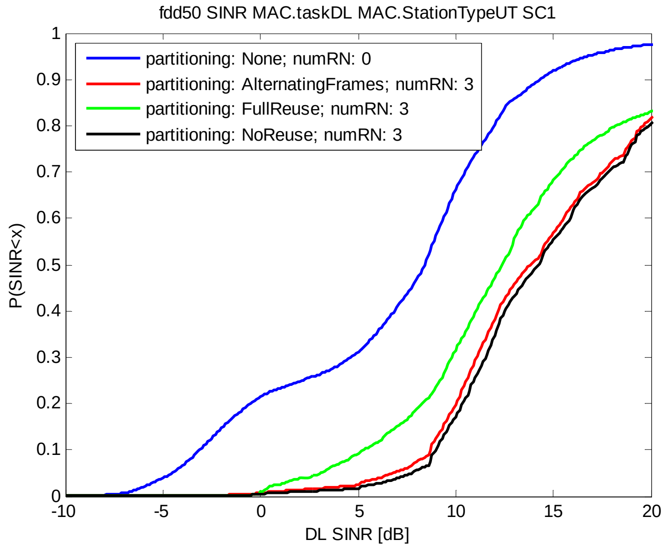


Figure 3-10: CDF of DL SINR measured by User Terminals, offered cell load: 50 MBit/s.

Figure 3-11 plots the complementary cumulative distribution function of the observed DL end-to-end packet delay. End-to-end in this context means from the arrival at the BS until the successful delivery at the UT. The statistics involve only the successfully transmitted packets, not the ones discarded at the receiver after the CRC check. The CCDFs were measured at an average DL cell load of 50MBit/s - a load condition where saturation was not yet reached for any of the compared schemes (although the "Alternating Frames"-scheme starts reaching saturation, cf. Figure 3-8). Since the system model does not include any load control, measuring the delay in overload conditions would not have produced meaningful results (i.e. infinite delays).

The figure shows that under the given load conditions, 99.9% of the successfully transmitted packets reach the UT in less than 1.8ms in the single hop case. Approximately 50% of all packets are even transmitted within 1ms. The introduction of relay nodes raises the 99.9th percentile of the delay to only slightly above 3ms for those cases while 70% of the packets are even received in less than 2ms.

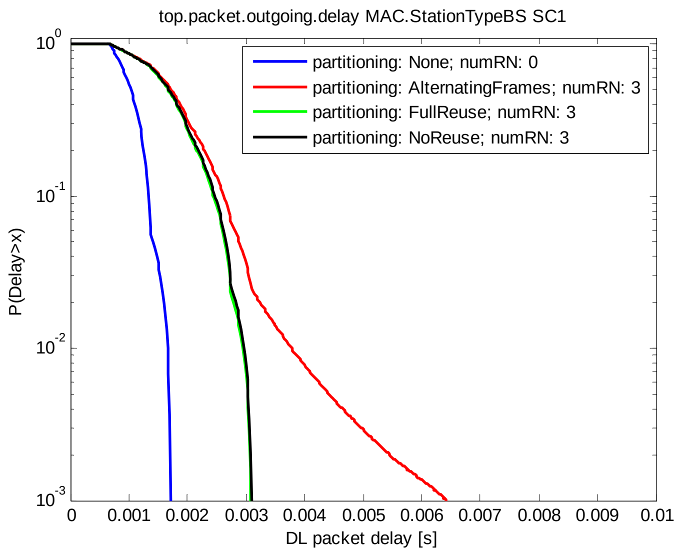


Figure 3-11: CCDF of DL End-to-end Packet Delay at a cell load of 50MBit/s.

3.2.3.2.2 Uplink

Figure 3-12 plots the avg. UL sustained data rate per user vs. the offered UL traffic (dotted line). It shows that in the single hop case, a considerable percentage of users are in outage, since even at low traffic loads, only about 70% of the offered traffic is carried. The introduction of relay nodes can somewhat improve on this situation. With increasing load, however, the system goes into saturation owing to congestion of the relay link. Here, adapting the partitioning could improve the situation

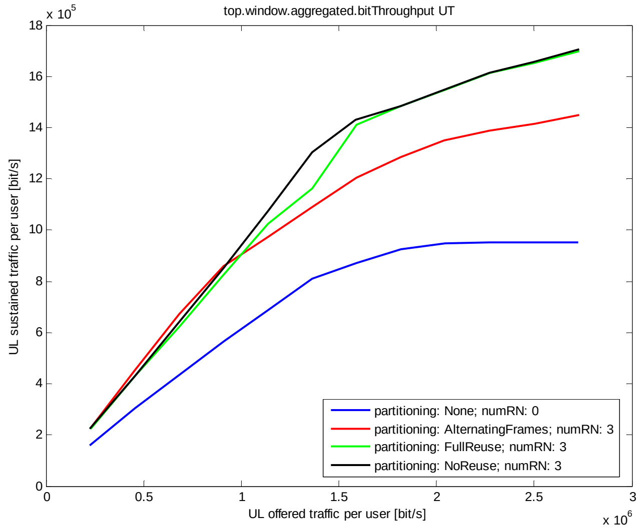


Figure 3-12 UL sustained traffic per user vs. offered traffic per user (44 Users per REC).

Another interesting property of the relay solution vs. the single hop case can be obtained from Figure 3-13. It shows the percentage of UL packets dropped owing to CRC errors. Two observations can be made here: (1) Relaying helps to substantially reduce the error rate, owing to the improved channel quality and (2) Error rates show a general tendency to decrease with increasing system load, which is caused by the fact that SINR predictions become more accurate as resource occupancy increases. As a consequence, the link adaptation mechanism is more likely to choose a suitable modulation and coding scheme than in the case of very bursty interference.

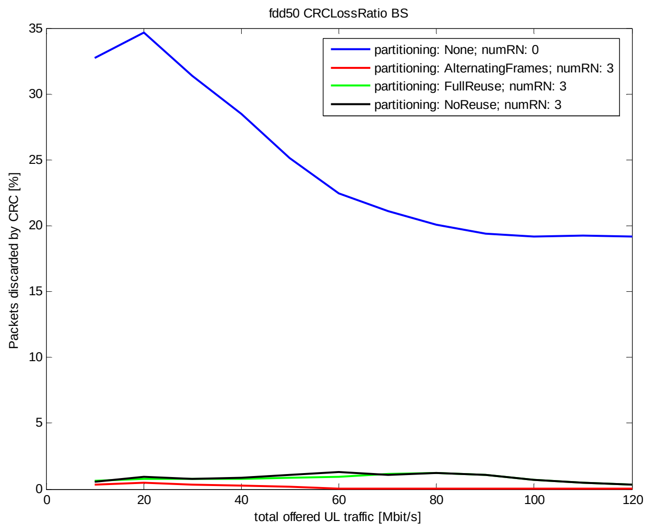


Figure 3-13: Percentage of UL Packets dropped by CRC in BS and RNs respectively.

3.3 Metropolitan area

3.3.1 Performance of reference design with improved resource partitioning and deployment options

As the results in Section 2.3 have illustrated, the baseline relay deployment and static resource partitioning does not perform well. Therefore, we present reference design and deployment options that improve the performance of the relay deployment compared to the baseline design. The impact of the different design and deployment options on the average user throughput is presented in Table 3-5. The same simulation setup than presented in Section 2.3 has been used for the evaluation.

The SINR of the received packets by UTs in the relay deployment is much higher than the SINR of UTs served in the BS only deployment for the baseline scenario presented in Section 2.3. This suggests that the reuse could be tightened and we study the performance impact of allowing both groups of RNs to use the whole bandwidth. This will be the reference scenario and the impact of further improvements will be presented as relative increase in average user throughput.

In the baseline deployment, the RNs are only one block away from the BS. Thus, the UTs between the BS and the RN can easily be served by the BS. Therefore we study the performance impact of using directive antennas pointing away from the BS to serve the UTs instead of omnidirectional antennas. This requires the use of two antennas at the RN but this small increase in hardware cost is outweighed by the increase in average user throughput of almost 50%.

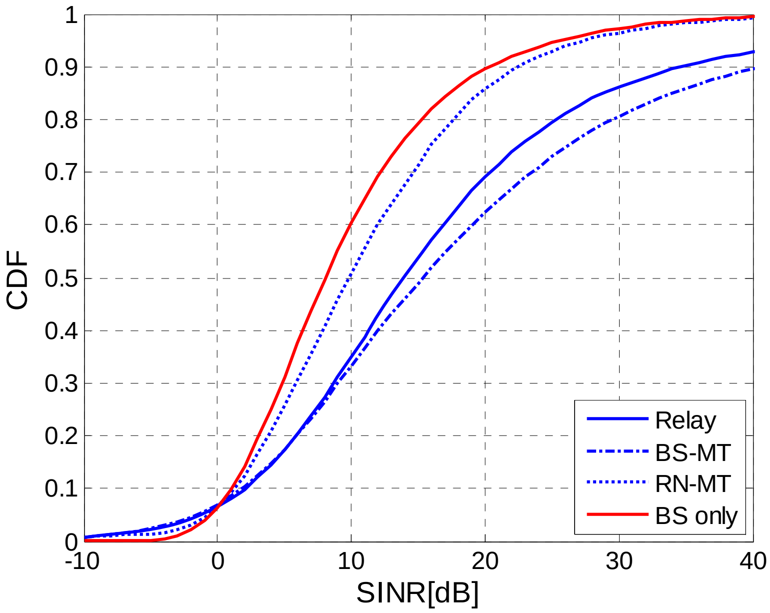


Figure 3-14: SINR distribution of the received packets for the relay deployment when RNs use the whole bandwidth compared to the same scenario without RNs.

As illustrated in Figure 3-14 the SINR of the received packets by UTs served by the RN is still much higher than the SINR in the scenario without RNs. This suggests that the reuse could be increased and we study the performance impact, when the BS is allowed to serve RNs while the RN is serving UTs. It increases the average user throughput by another 32%. However, the average user throughput is still slightly worse than for the same deployment without RNs, denoted as BS only deployment in Table 3-5. Next, we select the optimal number of frames within the super frame where the RN is allowed to serve its UTs. This number depends on the capacity of the BS-RN hop and the RN-UT hops. It is kept constant during the whole simulation and the same number is used within the whole network. Selecting the optimal number of frames for RN transmission improves the user throughput by an additional 24%. It is for further studies, if the performance of the relay deployment can be improved by allowing the RNs to transmit in different frames in different relay enhanced cells.

Finally, we compare the performance of the BS only deployment to the best relay deployment. After all the improvements, the average user throughput for the relay deployment is 18% higher than for the BS only deployment.

Table 3-5: Performance impact of different deployment and reference design options.

Deployment/design option	Relative average user throughput
Reuse 1 in frequency domain	1
Directive Antennas	1.47
BS and RN transmit at the same time	1.94
Optimal frames for RN transmission	2.52
BS only deployment	2.13

3.3.2 A low-complexity multi-user scheduling approach for REC with coordination

3.3.2.1 Introduction

In a relay enhanced system with the option of using SDMA at the transmitting stations, an algorithm is needed to decide which users should be served simultaneously by the SDMA scheme in each chunk. While doing so, inter-cell interference can be mitigated as well, depending on the amount of coordination available between the transmitters. As a simplification, the stationarity of the RNs can be exploited in the SDMA scheme during the scheduling process as presented in [WIN2D341] Annex G.1.

A multi-user spatial scheduling concept for SDMA based relay enhanced systems has been developed in WINNER. The development is based on the low complexity scheduling algorithm ProSched [FuDeHa05b] and its extension to interference avoidance scheduling for multiple co-operating base stations [FuDeHa06]. The ProSched approach inherently allows the consideration of both spatial correlation and optimal SDMA group size. It consists of two parts:

1. We use a scheduling metric which reflects the performance of one user's effective channel after any MIMO transmit precoding in the presence of a set of other users that are to be served simultaneously via space division multiple access (SDMA). The metric is an estimate of the Shannon rate with Zero Forcing precoding which can be considered an upper bound for other linear precoders. It has the following advantageous properties:

    - The ZF capacity of one user can be written with the help of an orthogonal projection into the intersection of the nullspaces of all other users' channels in the same SDMA group. The projection would normally have to be recomputed for every user in every possible SDMA combination. Instead, ProSched approximates the intersection by a product of projection matrices into the nullspaces of the single users. These matrices remain constant throughout the scheduling run, which dramatically reduces complexity. This means that the precoding matrices do not have to be computed while testing combinations. For details see also [WIN2D341].
    - Capacity as a metric reflects the impairment of spatial correlation and the effect of the average power assigned to a user, which again reflects the SDMA group size. It can be calculated based on channel matrix knowledge as well as on second order statistics channel knowledge.
    - A capacity based metric can be combined with proportional fairness in the sense of [Ho01] and with methods taking into account fairness and QoS in the form of user rate requirements such as in [SveWiOt04].

2. A tree-based best candidate search algorithm is carried out to reduce the number of combinations to be tested. It delivers beneficial user terminal combinations for all possible group sizes and allows in a second step a decision on the best group size based on the scheduling metric. Joint scheduling of all chunks is possible as well as tracking of the solution in time.

3.3.2.2 ProSched for multiple co-operating BSs

The multi-BS extension presented in [FuDeHa06] consists of two modifications. The first one is to extend the per-user scheduling metric by an estimate of the total received intra-cell interference power at each terminal. This estimate is obtained using the already available orthogonal projection matrices and requires only matrix multiplications and no additional matrix decompositions.

The second part of the multi-BS extension is a virtual user concept (see also [WIN2D341]). The tree based search algorithm is no longer executed on user numbers, but on numbers representing all allowable combinations of users and transmitters (denoted, in the example below as user#@basestation#). In this way, the underlying algorithm stays the same except for the interference term that is to be taken into account when virtual users belonging to the same transmitter are grouped. The approach allows for hard and soft handover scheduling with the difference that in the case of hard handover, a virtual user is deleted from the tree once it has been assigned to a candidate group. In the case of soft handover, multiple transmitters may serve the same user with the help of another dimension such as orthogonal codes, which has to be taken into account in the metric by a division. Examples for soft and hard handover are given in Figure 3-15 for the case of two BS and 3 users. The identified candidate groups are displayed in yellow. In the last step of the algorithm a selection between them is made. To that extend, soft and hard handover are system designers choices whereas extension of the algorithm can be thought of to provide an automated choice.

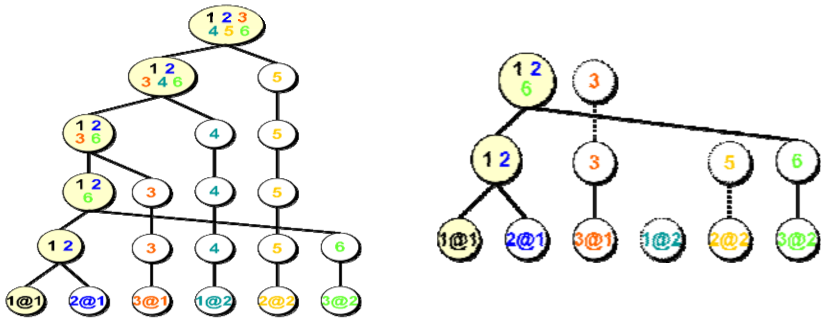


Figure 3-15: Example scheduling runs for soft and hard handover.

3.3.2.3 Extension to REC with coordination

Based on the version for multiple base stations, the spatially beneficial transmitter/receiver combinations can also be estimated in a REC. When the RNs are half duplex, they can be treated as user terminals in the time slots when the RNs receive. And when they transmit, they become additional base stations for the algorithm. Full duplex relay nodes could be supported in a similar fashion.

A key element of the extension is a model of a buffer at the RNs: RNs can only transmit as much as they have received before. Each RN's buffer is implemented as one number rather than storing a vector for each user. The buffer is kept in *bits/sec/Hz* because no exact time reference is needed for this study, since relative performance is shown rather than absolute values.

To generate the buffer levels for each UT needed in the scheduling metric we proceed as follows: When a RN is scheduled for reception, its currently achievable rate is added to its buffer. When a RN is scheduled for transmission, it is assumed that the buffer for transmission to each UT has been loaded optimally based on the achievable rates of the attached users in the current time slot (since we target maximum sum rate rather than user specific quality of service constraints). In real systems, this knowledge is of course not available a priori and represents a simplification which is justified because the channel changes only gradually. In other words, the situation in the time slot in which the buffers would have been filled can be assumed to be similar to the situation when transmission takes place. To generate the user specific buffer levels out of the single value buffer of a RN, the RN buffer figure is distributed via a standard water pouring algorithm on the UTs. To do so, the UTs' achievable rates when served from a certain transmitter represent the squared coefficients of the channels to be loaded and the RN buffer number is the power to be distributed.

To summarize, the benefit of ProSched is that during any testing of user assignments, the precoding solutions at each base station do not have to be re-computed but can be estimated with the help of fixed orthogonal projection matrices. The same applies to the interference which is different for each possible user assignment – it can also be estimated without knowing the final precoding solution. Additionally, ProSched may work with rank one approximations of the users' long term channels, reducing the required overhead dramatically.

3.3.2.4 Simulations and Discussion

In this section a proof of concept investigation is discussed in which the proposed approach of low-complexity centralized scheduling with interference coordination is compared to a reference approach without interference coordination.

The scenario under consideration is a Metropolitan area deployment based on the guidelines given in [WIN2D6137]. It differs from previous recommendations mainly by the following points:

– For interference avoidance, the operation of the RNs in at least two groups using different resources is recommended.
– RNs are also placed in the vertical streets, thus increasing the occurrence probability of line of sight (LOS) conditions in the channel.
– RNs now have omnidirectional antennas.

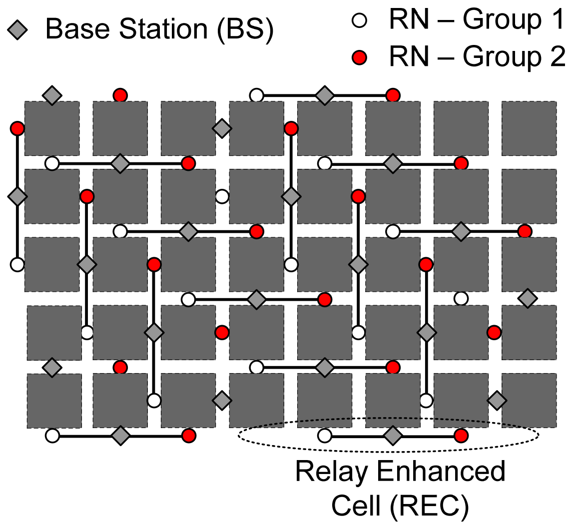


Figure 3-16: Sketch of microcellular cell layout with relay nodes which was implemented except for the transmitter on the edges.

Performance figures are given per square meter to allow some independence of the deployment section size. For the same reason, the total number of users in the system is not fixed, but is obtained from a user density per square meter which was set to $10^{-5}/m^2$. Compared to the previous investigations in [WIN2D341] [FKKH07], all rates are now bounded to *4.8 bits* per channel use, to take into account the fact that the system performance is modulation and coding limited (part of the so-called Shannon fitting procedure).

The basic system design is close to that of [WIN2D351]: Relays do not transmit and receive at the same time, resulting in the TDD frame structure also given in that reference. Only two hops are considered.

Simulation parameters are kept close to those of [WIN2D6137], except for the restrictions due to the reference method (see below) and for a change in base station antenna element elevation gain, which is set *8 dBi* instead of *14 dBi*, corresponding approximately to an assumed beam width of 60 degrees in elevation. Indoor users are not present in this simulation.

3.3.2.4.1 Description of reference method used for comparison

To be independent of the choice of space-time processing technique in the reference method, it is based on the theoretically achievable maximum sum rate under sum power constraint when channel knowledge is available at the transmitter (aka Dirty Paper Code Bound). The approach is an updated version of the one used in [WIN2D341] and published in [FKKH07], see below. The DPC bound rates are computed using the frequency flat, iterative uplink algorithm of [JIND05]. As a consequence, the study is limited to one subcarrier and the possibility of using OFDMA (which is given in the basic design of [WIN2D351]) cannot be investigated. This is due to the fact that in the literature no such algorithm was available when this research was started to treat also the space frequency power loading problem at the same time. A simplified frame structure is used such that one instance of the DPC algorithm is run per drop of the channel. Doppler effect is not analysed.

When a system with SDMA and relaying is considered, a scheduler is needed to assign the users to the transmitters. A genie-like scheduler is used and the RNs have a data buffer. The simulation steps for the reference performance are as follows:

1. Compute the DPC bound rates for all users when served by each one of the BSs and RNs separately, assuming independent single cell systems with one transmitter only. In the odd time slots RNs do not transmit but are also users (receivers). In the even time slots, the RNs act as BSs.
2. Genie-like scheduler knowing all achievable rates: Decide on the assignment of users to RNs and BSs based on the achievable DPC rates from step 1 (no interference considered in this step, suboptimal).
3. Recompute DPC covariance matrices for the newly assigned groups (second run of DPC algorithm required).
4. Perform uplink-downlink conversion of the newly computed covariance matrices as in [VJG03].
5. Compute downlink rates for the entire system WITH interference (all transmitters) using the downlink DPC covariance matrices from step 4 and taking into account a buffer level at the RNs: The role of the RNs depends on the time slot number. When the RNs receive, they fill up their buffer. When they transmit, the achievable rates of the UTs assigned to RNs is limited by a user specific buffer level of the serving RN (see the ProSched for REC description for how the buffer is implemented).

3.3.2.4.2 Discussion

The ProSched algorithm exists in variations with different complexity. The version simulated here uses rank one reduced bases of the users' subspaces to compute their nullspace projection matrices, which was originally meant for complexity reduction. In this setting, however, it allows to reduce considerably the overhead data to be transmitted to the central intelligence. This kind of overhead was not estimated, but is certainly present in both the reference method and the more practical method.

The precoding scheme used together with ProSched is SMMSE with dominant eigenmode transmission [WIN2D341], which is the reference scheme proposed in [WIN2D6137]. We also show the performance of the proposed reference method taking into account the resource sharing between two groups of RNs as proposed in [WIN2D351] and implemented in time direction.

It can be seen in Figure 3-17 that the proposed low complex scheduler performing joint interference avoidance together with low complex precoders increases the probability of achieving high rates in a wide range of the graph but suffers a slight drawback in peak throughput, likely due to the suboptimality of the precoder. Note that precoding is done separately for each transmitter but that the presented coordinated scheduler takes into account the predicted interference which depends on the selection of the users. The interference generated is different for each possible user assignment requiring different precoding matrices at each transmitter. However, the ProSched interference prediction scheduling requires no additional computation of any precoding matrices during the testing of combinations. The reference performance is based on the maximum rates that each transmitter can theoretically achieve when serving its assigned users as well as a genie scheduler which does not perform interference avoidance. To that extend the gain that is visible stems from interference avoidance.

Note that an even higher gain can be expected in a highly populated scenario (the number of users simulated was limited due to complexity) due to higher selection diversity. Furthermore, in an OFDM system, more degrees of freedom are available for interference avoidance.

Furthermore it was observed that non-intelligent interference avoidance in the form of time-sharing (i.e., forming two RN groups in time) may reduce the achievable rates (dashed curve). This conclusion may also change when the number of users in the system is increased.

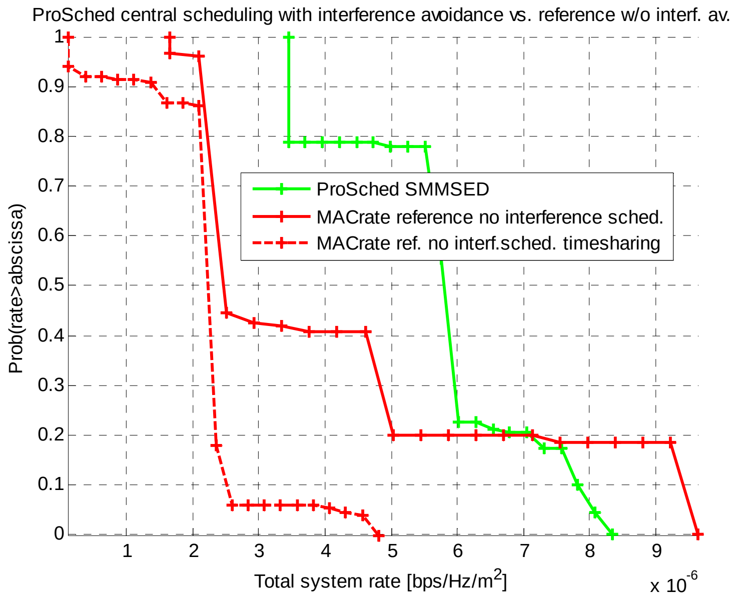


Figure 3-17: This figure shows the probability of exceeding a certain total system throughput for ProSched with interference avoidance using SMMSE dominant eigenmode transmission versus a reference based on the theoretically achievable maximum sum rate and a centralized genie scheduler without interference avoidance. The total surface was 2027200m^2. It can be seen that the proposed scheduler suffers a slight drawback in peak throughput (due to the suboptimality of the precoder), but increases the stability in a wide range of the graph. The absolute figures are, however, of limited value: Overhead present for both methods will reduce them significantly, but less for the ProSched method as said above. And both schemes will suffer from outdated and erroneous channel state information in the same way, since they are based on linear precoding.)

3.4 Local area

In this section the performance analysis for the local area scenario is presented following the baseline assumptions for relaying given in Section 2.4. Three cases are analysed: direct transmission, single path (conventional) relaying and relay node to relay node cooperation (cooperative relaying). Based on the achieved results some remarks regarding the applicability of the latter transmission type to the local area scenario are drawn and additional comments on relay nodes positioning are given. Additional conclusions and results are also expected in the final local area concept group deliverable [WIN2D61312].

3.4.1 Simulation assumptions

Simulations were performed according to the assumptions for indoor environment given in [D6.13.7] and taking into account the specific parameters outlined in Table 3-6. Since the scenario under investigation is symmetric, the simulation area was limited to a set of 10 rooms located in the right bottom part of Figure 2-11, i.e. around RN3. Therefore two RNs (green squares number 2 and 3) were used only and they were coordinated by the BS (red square number 0) located in the centre. At this stage no link adaptation was employed and temporarily QPSK modulation without coding was used. This of course has some implications on the presented results and it will be discussed further in the relevant subsection. Channel modelling was limited to AWGN channel and A1 NLOS propagation model was used not only between RNs and UTs, but also in the case of the links between BS and RNs. This remains in contrast with [WIN2D6137] but seems well justified due to the existence of walls. Additionally no outdoor users were taken into account and an average interference power level of -135 dBm per subcarrier was assumed.

Table 3-6: Simulation parameters.

Parameter	Value	Comments
Carrier frequency	5.0 GHz	
Channel bandwidth	100 MHz	

Number of cells	1	Indoor scenario
Distance BS – RN	27,95 m	
Spatial processing	Distributed OSTBC	RN-RN cooperation case
BS number of antenna per sector	1	
RN number of antenna	1	
UT number of antenna	1	
BS transmission power	21 dBm	
RN transmission power	21 dBm	
UT transmission power	21 dBm	
Retransmissions (ARQ, HARQ)	No	
Segmentation and Re-assembly	No	
Link adaptation	No	Under implementation, temporarily QPSK modulation without coding was used
Channel modelling	AWGN channel	A1 NLOS Room-Room model used for both BS-RN and RN-UT links (also for Room-Corridor transmission)
Mobility	Yes	
Resource scheduling	Fixed	Each user was assigned 1 chunk (8 subcarriers and 15 OFDM symbols)
Resource partitioning	Fixed	According to Figure 3-18
Selection of best RAP	Signal strength	
Traffic model	Constant Bit Rate (CBR)	

Moreover, each user was assigned one chunk, i.e. 8 subcarriers and 15 OFDM symbols and resources were partitioned according to the scheme depicted in Figure 3-18. The structure of the superframe was defined according to [WIN2D6137] and radio resources were partitioned in both the temporal and spectral domains. Similar pattern was repeated twice within the duration of a superframe. First, the resources were assigned to the base station and after that to different combinations of RNs. As a result a maximum of 3 RNs could have been active at the same time.

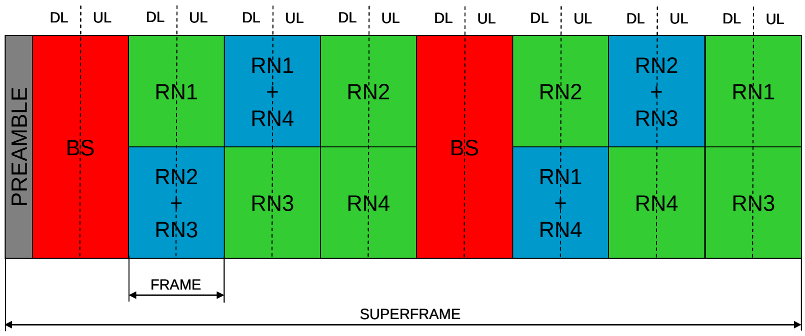


Figure 3-18: Radio resource partitioning.

3.4.2 Investigated configurations

This contribution is a follow-up to the description of the Static REACT algorithm provided to [WIN2D352], where BS selects RAP or cooperating RAPs and is responsible for resource partitioning and scheduling. The following relaying strategies could be taken into account (see Figure 2-11):

- BS serves the users (yellow squares) within its closest vicinity (e.g. user terminal number 11) either by itself or in cooperation with one or two relay nodes (e.g. 2 and 3).
- The users located farther should mostly gain from the possibility of conventional relaying (i.e. a user terminal is fed by one relay node only), cooperative relaying where the base station and one or two RNs are involved, or cooperation of two RNs (without engaging BSs).

Static REACT at the BS is assumed to use information about power level of the signals received by UTs from different RAPs, as well as the power level of the signals received from the BS by the RNs This information is reported to BS for the purposes of facilitating the selection of cooperating RAPs and updating the routing table accordingly. Figure 3-19 contains an illustrative routing table which is filled in according to the scenario presented in Figure 2-11. The base station can adapt to the current network load and QoS requirements and serve the destination user terminal (e.g. number 15) according to the aforementioned strategies, i.e., directly, in cooperation with the relay node 2 or 3 as well as both of them or, last but not least, via the virtual antenna array VAA(2, 3) (RN-RN cooperation).

	Destination	Next	Hop count
1	15	15	1
2	15	2	2
3	15	3	2
…	…	…	…

Figure 3-19: Example routing table at BS.

The results presented in the next subsection pertain to the following cases: direct transmission, single path (conventional) relaying and relay node to relay node cooperation (cooperative relaying). The complete performance evaluation of Static REACT with dynamic selection of relay node(s) and cooperation method is cannot be shown yet because the link adaptation is being implemented and the lack of coding causes a performance degradation especially in the case of RN-RN cooperation. Those results are expected, however, in the final local area concept group deliverable [WIND61312].

3.4.3 Simulation results

The relative user throughput (according to RAP deployment outlined in Figure 2-11) for direct transmission and for single path relaying is shown in Figure 3-20A and Figure 3-20B respectively, whereas the corresponding results for RN-RN cooperation are presented in Figure 3-22A. The relative throughput is presented instead of real values because no link adaptation was performed and only one modulation scheme was used. Those results were obtained assuming the aforementioned certain average power level of interference and they show that it is possible to make up for the performance degradation visible in Figure 3-20A when single path relaying is employed. Unfortunately the gain provided by RN-RN cooperation seems almost invisible as compared to the single path relaying case. One of the reasons is that since no coding was used, the first hop(s) error(s) could have propagated. Those errors are more harmful in the RN-RN cooperation case because they are likely to appear on either of two feeder links. This is not the main reason, however, and the lack of coding is expected to be improved with regard to the results prepared for the final local area concept group deliverable [WIN2D61312].

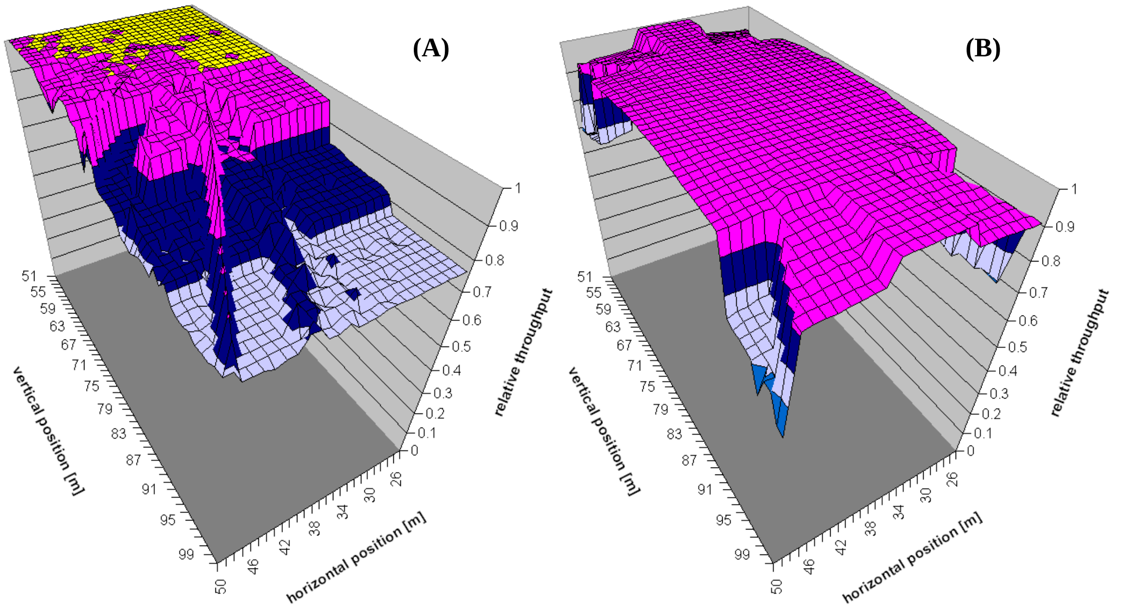


Figure 3-20: Relative user throughput for direct transmission (on the left) and for single path/conventional relaying (on the right).

The more important aspect is that according to the A1 NLOS propagation model each wall between rooms attenuates the transmitted signal by 5dB. As a result the power levels of the signals received be the destination UT from both cooperating RNs may differ e.g. by 15 dB. It means that quite often the signal coming from the other relay node (i.e. RN2 in Figure 2-11) is not strong enough to provide the expected improvement in performance. Consequently, in this case, it is impossible to gain from spatial-temporal processing provided by cooperating RNs.

The conclusion is that RNs should be located more densely to make it possible to choose those two of them which are separated from the UT by more or less the same number of walls. Further, the link between BS and RN should be good and the number of walls crossing the feeder links should also be taken into account. An example test set-up is shown in Figure 3-21 where both cooperating RNs are located in the area of interest (i.e. the set of 10 rooms located in the right bottom part of the scenario). The results are depicted in Figure 3-22B show improved performance and therefore prove that the use of Static REACT as a mechanism for dynamic selection of RN or RNs and transmission method will be well justified. The relevant results are planned to be delivered to the final local area concept group deliverable [WIND61312]. Based on them it will be also possible to perform the cost analyses showing whether it is worth to trade a more dense deployment cost for a better performance.

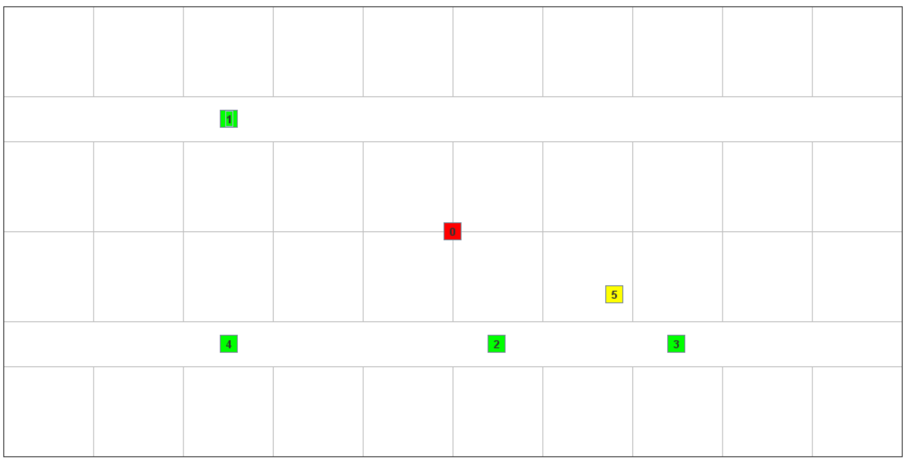


Figure 3-21: Modified deployment of RNs in LA scenario.

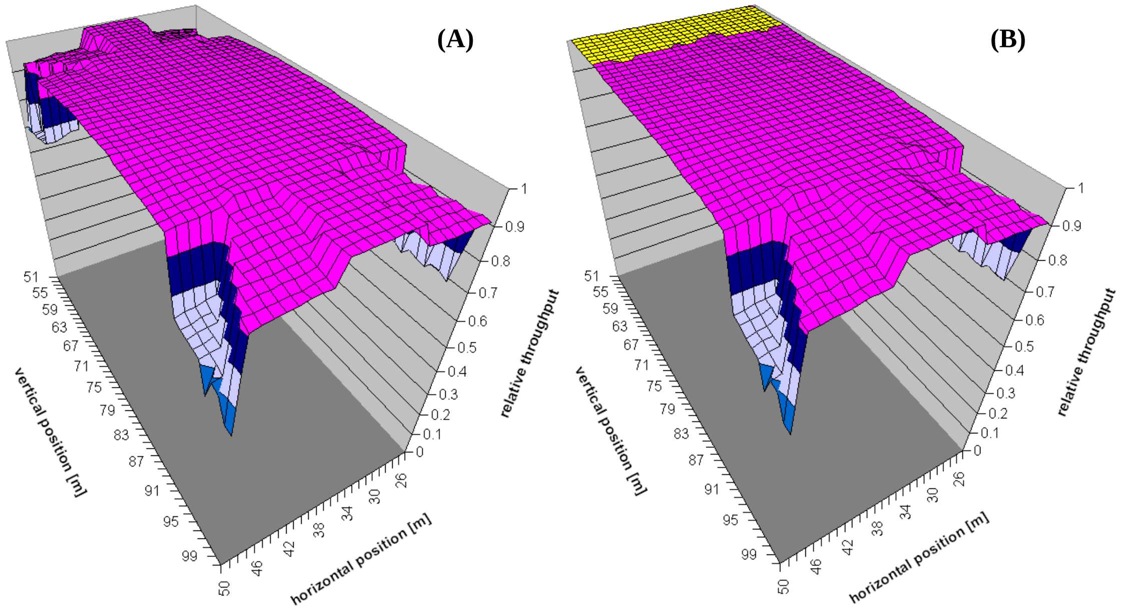


Figure 3-22: Relative user throughput for RN-RN cooperation according to both the baseline relay deployment shown in Figure 2-11 (on the left) and the modified relay deployment shown in Figure 3-21 (on the right)

3.4.4 Conclusion

In this section the analysis of the performance of different transmission strategies in the local area scenario was presented. It was concluded that one can gain from RN-RN cooperation when more dense deployment with smart cooperating RAPs selection is considered. Additionally the plans regarding the delivery of additional results and cost analyses were outlined.

3.5 Summary and conclusion

3.5.1 Summary

Chapter 3 has shown a range of performance results obtained from simulations. The simulations have been performed by different partners with their respective simulation tools in the context of the CG scenarios. As compared to the baseline scenarios (cf. Chapter 2), partners have investigated additional features and algorithms for the reference design. In the Wide Area CG scenario, Section 3.2 gives performance results on Multicast-/Broadcast Transmission (3.2.1), dynamic resource partitioning in combination with GoB-based interference mitigation (3.2.2) and static, load-based resource partitioning in combination with SDMA at the Base Station (3.2.3).

Section 3.2.1 shows that the SINR gains obtainable from the use of RNs allow to use Multicast-/Broadcast-Schemes more efficiently than in Single-Hop deployments - the number of users required for a multicast group to outperform point-to-point links can be reduced through the use of RNs. Section 3.2.2 indicates that relay-based deployment can outperform a BS-only deployment in terms of overall spectral efficiency. The observed improvements are about 20 percent. The contribution also shows that the relaying gains can only be attained under the assumption of a dynamic resource partitioning scheme. This property will be even more visible when switching from full-buffer traffic models to more realistic packet arrival processes, which lead to an inhomogeneous distribution of traffic in the REC. Section 3.2.3 gives simulation results based on a simple Poisson packet arrival model. The attainable spectral efficiency figures are similar (between 1.5 and 2 Bits/s/Hz) to the ones given in Sec. 3.2.2. and the results support the statements made there about the necessity of a dynamic adaptation of the partitioning. Furthermore, Uplink performance results from Sec. 3.2.3 show the importance of RNs when it comes to providing area-wide cell coverage. Owing to the limited output power assumed for the WINNER user terminals (24dBm), the Uplink range is limited such that in the Single-Hop case, not the entire cell area can be covered and a large percentage of users (>20 percent) remains in outage.

Section 3.3 gives performance results obtained in a Metropolitan Area CG scenario applying elaborate partitioning/reuse schemes. While the baseline resource partitioning assumptions have not shown to be well suited to the MA scenario, Section 3.3.1 shows that - similar to the WA case - improved resource partitioning can improve the performance of relay-based deployment by a margin of about 20 percent over the single-hop case. In these studies the resource partitioning in the time domain has been the same for each relay enhanced cell. It is for further studies, if allowing each REC to change the amount of frames where RNs transmit can improve the performance. Section 3.3.2 presents an intelligent, centralized interference-aware scheduling algorithm for relay-enhanced cells and compares its performance against simple, interference-agnostic scheduling algorithms. At the cost of slightly reduced peak system throughput, a substantial gain in average system throughput can be achieved using ProSched. These studies give an upper bound on the achievable gain by centralized scheduling.

Section 3.4 compares the performance of different relay-based transmission schemes (single-path and cooperative relaying) in a Local Area CG scenario. The results currently available show that the use of RNs improves the overall performance (given as “relative throughput”, which can be understood synonymously as 1-PER), while the cooperative schemes show no substantial improvement over the single-path relaying case. In addition, simulations have shown that cooperation between relays which show strongly varying channels towards the destination user may be difficult to do.

3.5.2 Conclusions

The resource partitioning schemes investigated and the performance results presented in Chapter 3 can be condensed into the following statement:

In all investigated CG scenarios, the deployment of relay nodes has shown the potential to improve the level of coverage - especially to overcome uplink power limitations - while achieving similar or even better spectral efficiency figures as the single-hop deployments. The latter improvement can however only be realized by the usage of intelligent and dynamic resource partitioning and reuse schemes to adapt the available capacity on the relay and the access links to the actual distribution of the offered traffic within the Relay-Enhanced cell.

4 Cost analysis for relay deployment

4.1 Introduction

It is important to emphasize that the main motivation for a relay based deployment is to decrease the overall network cost, while still meeting the target performance (e.g. in terms of capacity density and coverage area) that we have specified for a given area. In fact, one of the latest proposals from the Wi-MAX community, in order to reduce total deployment cost for a given system performance requirement, has been the recent creation (in 2006) of the IEEE 802.16j working group, devoted to the development of Mobile Multihop Relay (MMR), whose basic idea is the same as the relaying concept in WINNER, that is, to save costs and extend the network coverage into areas where the direct connection to the network using fixed line connections is economically and/or technically infeasible. Notice besides that one of the main operational expenditure (OPEX) drivers in mobile networks today is the requirement to connect the different radio access points deployed in a certain scenario (BSs or RNs) to the network, and so the use of simple relay nodes (lower cost and complexity than BSs) controlled by BSs, allows minimum installation cost. In short, the economic benefits of relay nodes based on lower CAPEX and OPEX than base stations (wireless backhaul, lower site acquisition costs, less costly antennas, lower cost and complexity, and faster deployment) are the main motivation for the inclusion of these new nodes in the WINNER system. Finally, and from an operational point of view, in case a relay stops work properly, the users served by this relay could obtain the service through its base station, probably with less throughput but avoiding a drop of the communication.

So in this chapter we have included some important aspects concerning the cost analysis for relay-based deployments, like the extension of the cost methodology based on iso-performance curves to the uplink direction, as well as the results of different kinds of simulations performed for evaluating the relay based deployment from a cost analysis perspective in two of the three WINNER scenarios, Wide Area and Metropolitan Area.

4.2 Relating the uplink to the downlink in the cost methodology

4.2.1 Introduction

A cost methodology based on indifference or iso-performance curves was introduced in [WIN2D351], enabling a trade-off between the number of relays and the number of base stations in a network. Thus, the least-cost network configuration could be determined. The methodology was developed in [WIN2D6136] to enable comparisons between three types of access points: for example, base stations, relays and micro-cells. Subsequently, in [WIN2D352], it was shown how alternative deployment options and spatial processing influence the shape of the indifference curve.

So far, the methodology has been restricted to a single "service" or direction of flow, for example the downlink. We now extend the methodology to include both the downlink and the uplink. It will be apparent, however, that multiple services (for example, voice and data) flowing in the same direction could also be compared in the same way.

4.2.2 The multi-service indifference map

Figure 4-1 illustrates an indifference map containing indifference curves for the uplink and the downlink of a multihop cellular wireless network. Although the service requirements for any point on an indifference curve must be the same, they need not be the same for each curve on the map. However, in this example, the service requirements are the same for the uplink and the downlink: a capacity density of 0.37bps/Hz/km^2 and 95% area coverage.

It can be seen from the graph that the uplink behaves differently to the downlink, and that the same configuration of base stations and relays only meets the requirements for both directions where the two indifference curves cross. However, this point is not necessarily the least cost configuration.

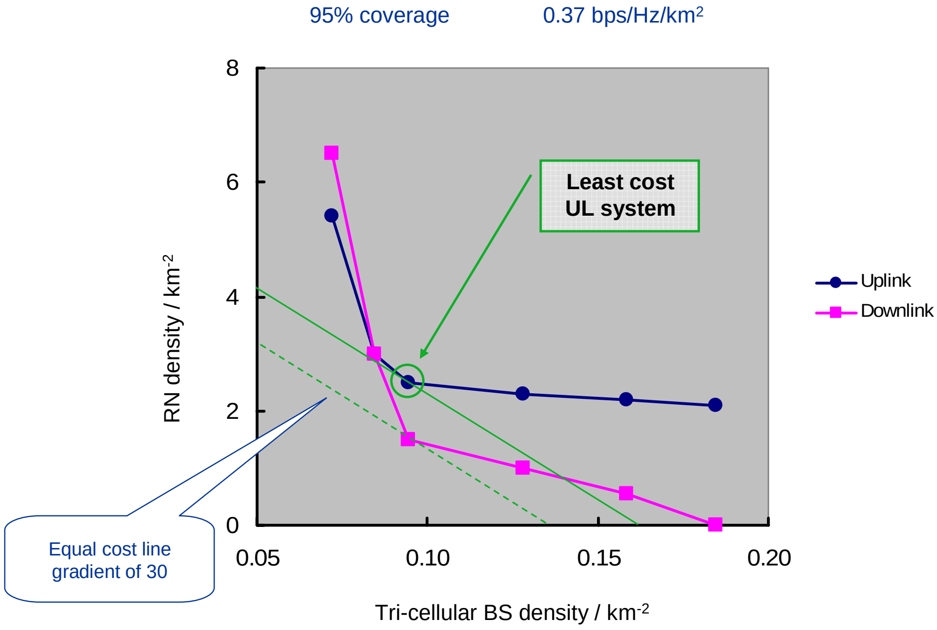


Figure 4-1: Indifference map comparing uplink and downlink configurations.

4.2.3 Least-cost network

To determine the least cost configuration, which meets the requirements of both the uplink and the downlink, two equal-cost lines are drawn. For the example in Figure 4-1, a base station to relay cost ratio of thirty is assumed, which determines the gradient of the equal-cost lines. The equal-cost line for the downlink is tangent to the corresponding indifference curve closer to the origin, indicating that the least-cost configuration for the downlink has a lower cost than for the least-cost uplink configuration. However, the least-cost downlink configuration does not meet the service requirements for the uplink, which requires a higher density of relays for this density of base stations.

Assuming that the same relays will serve the uplink and the downlink, the least-cost configuration for the system as a whole is therefore determined by whichever of the points where the equal-cost line is tangent to an indifference curve is furthest from the origin. In Figure 4-1, the limiting direction is the uplink.

4.3 Wide area

In this section the approach is to create an iso-performance curve to evaluate different multi-access configurations consisting of macro BSs and relays. The concept of iso-performance curves was introduced in [WIND351] and has been extended in [WIND352] as well as in above sections, and here only a very brief summary is provided.

The core idea with the approach is that different deployment alternatives can provide the same service to a network area. In this section the different deployment alternatives are different mixes of macro BSs and RNs. One alternative is that only BSs are deployed to serve the traffic in the network area. Other feasible deployments, i.e. other points on the iso-performance curve, consist of less BSs and more RNs. A sequential decrease in the number of BSs will result in a sequential increase in the number of RNs. It should also be pointed out that there is a lower limit to the number of BSs that needs to be deployed in the network, i.e. the deployment cannot consist exclusively of RNs.

In [WIN2D6136], and specifically in [WIN2D61313], a deployment methodology that enables the creation of an iso-performance curve is developed. The starting point of this scheme is a network area with uniform or non-uniform traffic density, and the next step is to sequentially deploy RAPs (e.g. macro BSs and RNs) until full coverage is reached. To evaluate whether all users are satisfied, a snapshot calculation of the resources in the network is performed. Only downlink traffic is considered. A detailed description of how radio resources are controlled is provided in [WIN2D61313], and here only an outline of the deployment procedure is given:

0. The deployment procedure in bullets 1-5 is performed for 10 different randomly generated non-uniform traffic maps. The plotted result is a mean value of these deployments. The procedure below is described for RNs as the complementary RAP, but it is also valid for micro BSs.
1. A traffic map with size 5×5 km is created.
2. a) An initial deployment consisting of 10 macro BSs is performed. These are unable to serve all the users in the network (only DL is considered).

   b) RNs are deployed until the users are satisfied. The result is the leftmost point in the curve, i.e. 10 BSs and around 42 RNs (the value is a mean).
3. a) Two additional BSs are added. Evaluate whether this deployment can serve the users by calculating whether the resources in the DL are sufficient; this is done for one snapshot.

   b) RNs are deployed until the users are satisfied. The result is a combined deployment of 12 BSs and 37 RNs.
4. Same as 3 a) and b). Another point in the ISO-curve is generated.
5. Continue until the users are satisfied with only BSs. In this scenario this is on average achieved by 28 BSs..

For every macro BS added to the initial deployment, the number of RNs or micro BSs required to achieve full coverage is naturally lowered. The deployment continues until the network is covered by macro BSs only. The outcome is depicted in Figure 4-2 below. Parameters used for the simulations are provided in Table 4-1 below

The resource partitioning model for the relay enhanced system is described very briefly. During the first of two phases, all RAPs (including BSs and RNs) transmit to the UTs; and, in the second phase, BSs transmit to the RNs or to the UTs. Interference is accounted for on all links. The feeding links between BSs and RNs are assumed to follow line of sight (LOS) propagation and other transmissions between RAPs and UTs follow NLOS propagation. Also, all the interfering signals in the network are modelled according to NLOS propagation.

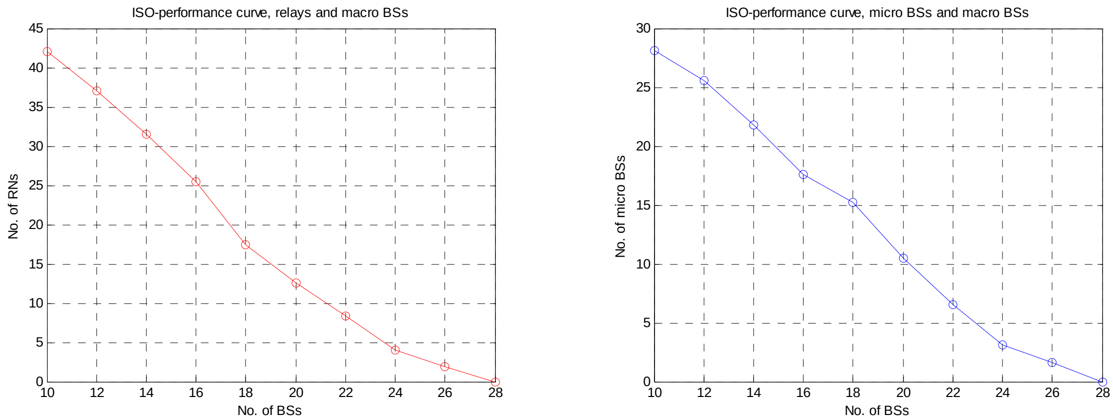


Figure 4-2: Indifference curves for RNs and micro BSs.

It is clear that the result is a line with constant slope for both the RNs and the micro BSs. This to some extent surprising result means that the economical trade-off between adding RNs or micro BSs compared to macro BSs, is independent of the existing macro BS density. In this case, the slope is around 3.3 for the RNs, thus implying that 3.3 RNs can be traded for 1 BS, still achieving equal performance. It also implies that if the cost of 3.3 RNs is lower than the cost of 1 BS, it is economically advantageous to deploy RNs, and this is independent of the existing BS density in the network. The same reasoning can be applied for the micro BSs case, where the slope is 1.55, indicating that 1.55 micro BSs can be traded for 1 BS.

Both complementing RAPs (RNs and micro BSs) perform well compared to the macro BS. One reason for this is the heterogeneity due to the traffic distribution and fading model, making it advantageous to deploy many smaller RAPs compared to a lower number of macro BSs. Furthermore, the urban propagation has a significant attenuation factor for NLOS transmissions.

Also it is interesting to compare the performance of RNs with the performance of micro BSs. The difference in the number of relays is about 50 % higher than the number of micro BSs (leftmost points corresponding to 28 micro BSs and 42 RNs). This implies that the RNs are economically beneficial if the micro BSs are 50 % more expensive than the RNs. In [WIN2D61313], the estimated cost difference between these two RAPs is estimated, and the assumption there is a cost difference of around 50 %. Consequently, it is hard to draw conclusions on the most cost efficient alternative.

Table 4-1: Parameters.

Parameter	**Value**	**Comments**
Carrier frequency	3.95 GHz DL	Only downlink
Macro BS tx power	46 dBm	
Micro BS tx power	37 dBm	Micro BS and RN has equal characteristics
RN tx power	37 dBm	
Macro BS antenna gain (omni)	10 dBi	
Micro BS antenna gain (omni)	2 dBi	
RN antenna gain (omni)	2 dBi	
Alpha NLOS (RAP → UT)	3.57	
Alpha LOS (BS → RN)	2.35	Feeding link BS to RN
Shadow fading	From D111	Both on RAP → UT and BS → RN
Traffic model	See [WIN2D61313]. Mean user density urban: 12100 users/km^2 Operator market share: 30 % Log normal traffic distribution with Standard deviation: 7 dB Correlation distance: 500 m Traffic per UT (busy hour): 2 kbit/s	

4.4 Metropolitan area

4.4.1 Simulations in real dense urban scenario

The purpose of these simulations is to validate the relaying concept from a cost perspective in a particular dense urban scenario (real cartography of Madrid), comparing different kind of deployments, with and without relay nodes, but with the same or similar performance from a capacity density and coverage percentage points of view. The simulations only contemplate the downlink direction and they are the continuation of the carried out in the previous deliverable [WIN2D352]. They are system level class III simulations (static or quasi-static behaviour of the system) based on a 3D ray-tracing model for the estimation of the SINR over a real cartography of Madrid city. The preliminary results indicated that the total cell capacity decreased when we included relay nodes, but then the service area enlarged. The reason for the reduction of the capacity was the inefficient resources partitioning used, and so it was decided to implement a strategic more efficient in order to reduced the wasted resources.

It is important to note that these simulations are focused in the comparison of traditional and relay-based deployments from a cost analysis viewpoint, and then not any protocol aspect has been considered, assuming a correct operation of all protocol functions, concentrating the analysis in the performance of the deployment exclusively from a radio propagation perspective.

Although the parameters used in the simulations as well as the procedures and methodology were described in the Annex A.2 and section 2.3 of previous deliverable [WIN2D352], in the Table 4-1 is showed the main simulation parameters, which are based on the baseline assumptions outlined in [WIN2D6137] for the metropolitan area scenario. Besides in the current simulations some important changes were adopted, which hereinafter are explained.

- In the deployments has been used a frequency reuse of 2 (f1: 3900-3950 MHz, f2: 3950-4000 MHz). The two sectors of a given BS are using the same frequency band, except the BS with two relays, in which case the two sectors make use of different frequency bands. This decision was taken after several proofs accomplished for minimizing the interferences in our particular scenario (eight horizontal streets per eight vertical streets, with two bi-sectorial base stations per street).

- We have defined a target user throughput of 2 Mbps in the whole of the deployment, that is, something equivalent to the Equal Throughput Scheduling, which provide to each served user the same throughput. The users with better spectral efficiency (single for sectors or mixed for relays) will be served until the allocated resources of the RAP are consumed.
- We use a flexible resource-partitioning scheme in the RECs based on a fair load balance in terms of the users with best spectral efficiency (single versus mixed). An iterative process for each REC beginning with a certain partitioning (7/5 and 3/5 for single and multi-hop communications respectively in two consecutive MAC frames), and searching the optimum partitioning from a capacity density perspective. This process is repeated for BS-RN and RN-UT links in order to minimize the wasted resources in the first hop.
- In this occasion we have utilized an active user density more realistic than in the first simulations campaign. The value of this parameter used in the current simulations is 1600 users/Km^2 (corresponding to a hot spot in a micro-cellular dense urban area). In order to reach this user density, the inter-distance of the common grid used in the simulations as reference points, was of 25 m instead of 10 m that was used in the first campaign. It is assumed that the users are fixed in the points of this grid.

Table 4-1: Simulation parameters used in real dense urban scenario

Parameter	**Value**	**Comments**
Duplexing scheme and asymmetry	TDD (1:1)	Only DL
Carrier central frequency (DL)	3925 MHz and 3975 MHz	Frequency reuse of 2
Channel bandwidth	50 MHz per sector	
BS location and height	Below rooftop at 10 m from the street floor	
Maximum transmit power per sector	37 dBm (5.012 W)	
Number of antennas per sector and type	1 antenna K733337XD	Similar radiation pattern to the proposed in WINNER baseline assumptions
RN location and height	Below rooftop at 10 m from the street floor	
Inter site distance of BSs in the same street	Around 600 m in vertical streets and 700 m in horizontal streets	In order to avoid either the cross-roads or streets corners
Number of sectors per BS	2	
UT height	1.5 m	
Elevation antenna gain for UT	0 dBi	
Receiver noise figure for UT	7 dB	
RN location and height	Below rooftop at 10 m from the street floor	
Maximum transmit power per RN	30 dBm (1 W)	
Number of antennas per RN and type	1 antenna with omni-directional pattern	
Elevation antenna gain for UT	7 dBi	
Receiver noise figure for RN	5 dB	

Distance between the sector of a BS and its associated RN	Around 300 m	In order to avoid either the cross-roads or streets corners

The Figure 4-2 shows the distribution of frequency bands and the resource partitioning used in the current simulations. The amount of resources dedicated to the BS-UT, BS-RN and RN-UT links respectively in the relay-based deployment, is adjusted to the intermediate results of the simulations, so that the allocated bandwidth to the BS-RN link in the first MAC frame depends on the spectral efficiency obtained in each site (sector or RN), and of course in the BS-RN link.

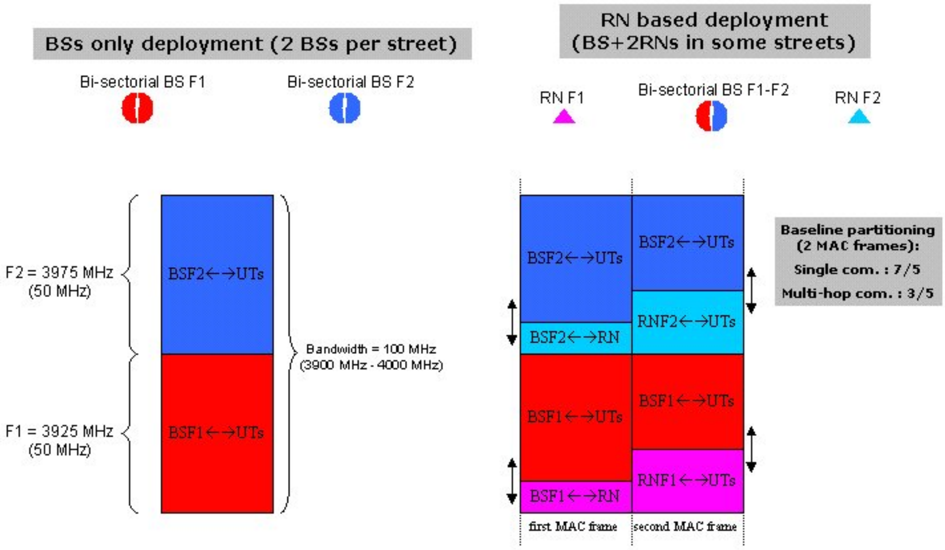


Figure 4-2: Frequency bands distribution and resources partitioning adopted in the simulations. The baseline partitioning for two consecutive MAC frames was 7/5 and 3/5 for single and multihop communication respectively, but in terms of the spectral efficiency showed by the users around a certain REC, the resources distribution was adjusted for each RAP (BS and RN) giving service at those users with better spectral efficiency (direct or mixed)

The RAPs included in the simulations correspond to the micro BS and the RN with output power of 37 and 30 dBm respectively, according to [WIN2D6137]. From a cost analysis perspective it is important to note that the micro BSs used in the simulations are composed by two sectors, each one with its antenna and equipment but sharing of course the site acquisition and transmission line costs.

As Table 4-2 shows, the simulated deployments, base stations only and relay based, tried to achieve the same performance and for at least five different configurations (one for BSs only and four for relay based) in order to apply the indifference curve methodology, and so to get the least cost deployment in terms of cost ratio between base station and relay node. Unfortunately due to the limitations of our particular scenario (area of 1300 m per 1300 m with irregular streets and size of blocks), the number of radio access points as well as its location were restricted to certain values so that it was impossible to obtain enough points (BSs and RNs configurations) with the same performance for delineating one iso-performance curve. In any case there were two deployments with the same performance, one using only BSs and the other one replacing two sectors by four relays. For the same reason and in order to avoid the location of RAPs near to the corners, the separation between adjacent BSs was 600 m in the horizontal streets and 700 m in the vertical streets. For the RECs the distance between the BS and its associated RNs was around 300 m.

Table 4-2: Different configurations used in the simulations for relaying concept validation

Configuration	**Number of BSs**	**BSs density (Km^2)**	**Number of sectors**	**Sectors density (Km^2)**	**Number of RNs**	**RNs density (Km^2)**
1 (BSs only)	32	18.93	64	37.87	-	-
2 (relay based)	30	17.75	60	35.50	2	1.18

3 (relay based)	30	17.75	60	35.50	4	2.37
4 (relay based)	28	16.57	56	33.14	8	4.73
5 (relay based)	31	18.34	62	36.69	4	2.37

4.4.1.1 Results of simulations

First of all and as starting point in our simulations we had to achieve a trade-off between the number of BSs to be deployed and the performance of the deployment, that is, between the total costs and the capacity and coverage that we have compromised. In this way, we obtained an optimal deployment locating two micro bi-sectorial base stations per street. For example we proved that a BSs only deployment with three BSs per street obtained only an increase of 5 % in the total coverage but practically with the same outdoors coverage, wasting besides part of the frequency band (50 MHz) allocated to each sector.

In order to characterize the baseline deployment using only BSs, it was decided to analyze the behaviour of the performance for different user throughputs. The Figure 4-3 illustrates this analysis, assuming a user density of 1600 users/Km2 (slightly upper of the typical for a hot-spot in dense urban scenario), showing for a given user throughput the capacity density and service area that it is possible to obtain for such deployment.

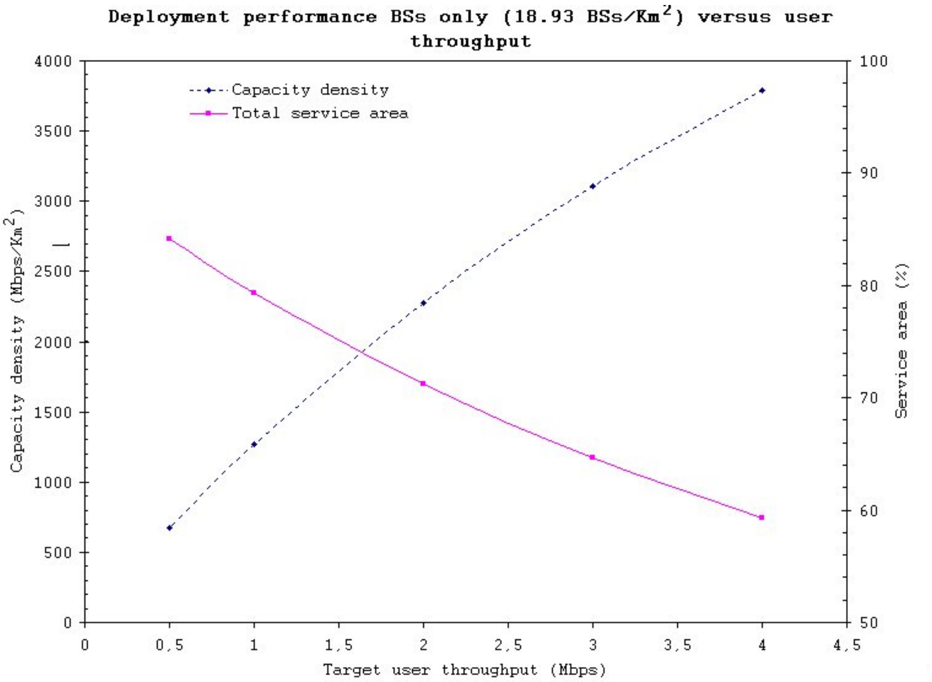


Figure 4-3: Variation of capacity density and total service area (outdoors and indoors) versus the common target user throughput for the deployment with BSs only (scenario area: 1.69 Km2, 8 horizontal streets per 8 vertical streets, 2 bi-sectorial micro BSs per street)

The Table 4-3 summarizes the results of our simulations highlighting the two configurations, one BSs only and another one relay based, which showed the same capacity density and coverage. As we can see the indoor coverage detected was very poor in all the cases due to the high frequencies used by the RAPs whereas the coverage along the streets was upper than 93 % for the best deployments. The spectral efficiency of the users was approximately in the range from 0.2 to 4 bps/Hz, being lower than 1 bps/Hz for 40 % of the served users (average of all RAPs included in the deployment).

Table 4-3: Performance in terms of density capacity and service area showed by each of the configurations used in the simulations for relaying concept validation

Configuration	Total number of active users @ 2 Mbps	Density capacity (Mbps/Km^2)	Total coverage (%)	Outdoors coverage (%)	Indoors coverage (%)
1 (64 sectors)	1925	2278.11	71.19	93.12	60.47
2	1850	2189.94	68.44	89.49	58.15
3	1866	2208.88	69.03	90.26	58.64
4	1824	2159.17	67.47	88.23	57.35
5 (62 sectors + 4 RNs)	1930	2284.62	71.39	93.36	60.62

In the Figure 4-4 is showed the service area for each of the two deployments (BSs only and relay based), which presented the same performance in terms of coverage and capacity density. Note that in spite of the practically total coverage along the streets obtained in both deployments, there are some outage zones mainly in the external part of the scenario, causing an important reduction in the total coverage of the deployment. Also it was observed some internal zones with a very poor spectral efficiency due probably to the particular characteristics of the surroundings buildings (height and materials). The only way to avoid these irregularities would be to carry out a detailed network planning (exact orientation and location of antennas), taking into account the peculiar features of these zones.

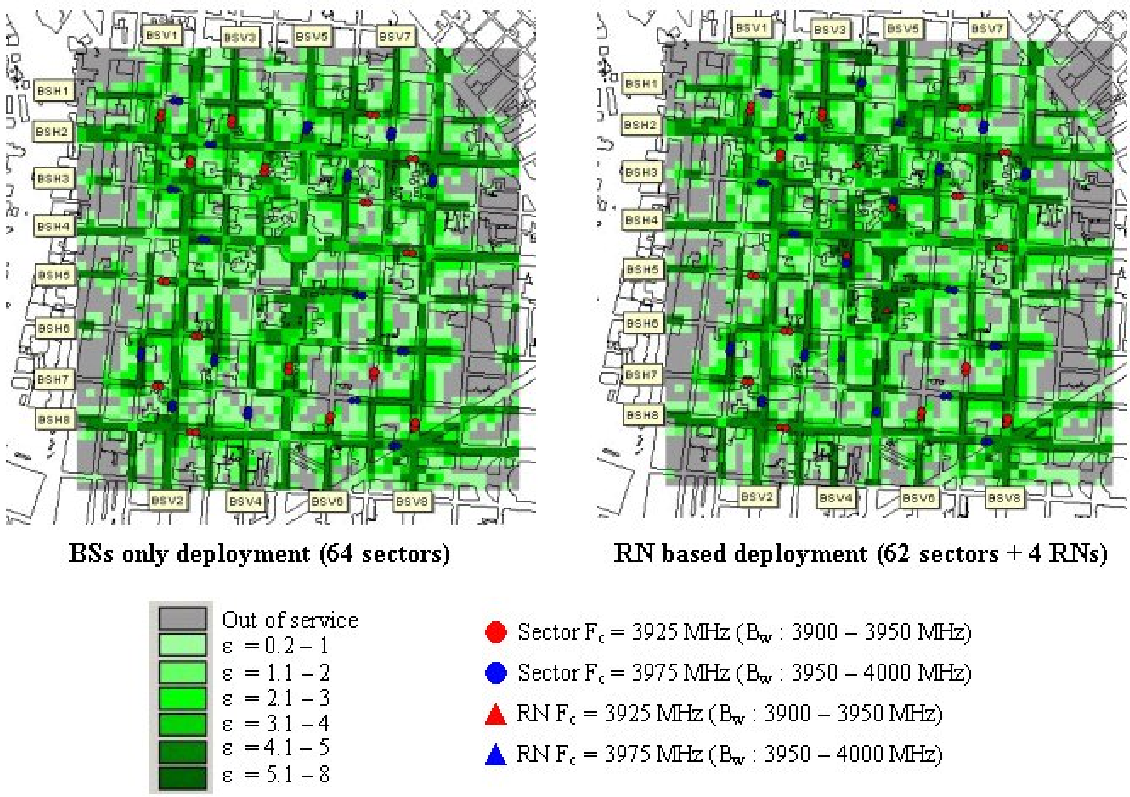


Figure 4-4: Comparison of the two deployments, BSs only and relay based, which exhibited the same performance in terms of capacity density and service area. The grey zones represent outage areas (users without service) due to a very bad SINR. The total service coverage area is 71.19 % and 71.39 % for the BSs only and relay based deployment respectively, assuming a target user throughput of 2 Mbps. The capacity density obtained in each case is 2278.11 (BSs only) and 2284.62 (relay based) Mbps/Km^2

Concerning the RECs (bi-sectorial BS with two relays) included in the relay based deployment, it is important to comment that the REC was approximately 1.6 times more efficient than a simple BS, that is, while a BS gives service to 50 users, the REC is able to serve at 80 users.

The final objective of our simulations is to demonstrate that a relay-based deployment in the particular metropolitan scenario used, is beneficial from a network cost point of view, and like the results show there was a relay based configuration with the same performance even slightly upper than traditional deployment. So we have demonstrated that using an efficient resource-partitioning scheme, it is possible to obtain a deployment exchanging BSs per RNs with the same network performance. Now depending on the costs ratio between BS and RN used in our particular scenario it will be better to deploy only BSs or include RNs. Regarding this topic and according to available literature [JFK+04], and preliminary estimations performed in WINNER project [WIN2D6136], the Table 4-4 provides some examples of CAPEX and OPEX for different RAPs (micro base station and relay node). The relay of this table has a transmit power of 33 dBm and it is the only one so far contemplated in the cost assessment example carried out in WINNER and included in the deployment cost analysis deliverable [WIN2D6136]. Note that this relay is not exactly the same than the used in our simulations, since the maximum transmit power used for the RNs in the simulations was 30 dBm instead of 33 dBm. On the other hand it is important to remark that the cost figures showed in this table are only cost examples based on estimations, and therefore the real cost could definitely vary depending on the deployment scenario and should be understood only as a demonstration basis. The OPEX costs are represented by their net present value (assuming a lifetime of ten years and a discount rate of 6%), and in this way the CAPEX and OPEX can be combined, for comparison purposes of different RAPs. According to this approach the total costs of a micro BS and a RN (output power of 33 dBm) are 40.79 and 26.6 K€ respectively, yielding a BS/RN cost ratio around 1.5.

Table 4-4: CAPEX and OPEX cost elements example for different RAPs

Cost Element	**Unitary Cost for CAPEX or Net Present Value for OPEX (K€)**	**Cost Type / Comments**
Micro BS Equipment	5	CAPEX
Micro BS Site Acquisition and Deployment	6	CAPEX / Small footprint
Micro Fixed Line Connection	0.05	CAPEX / Connection to mass-market ADSL line
Micro BS Site Rent, Maintenance and Power	23.4	OPEX / no back-up batteries
Micro BS Fixed line Connection Rent	6.24	OPEX
RN Equipment	7	CAPEX / Small footprint and not backhaul (max. transmit power of 33 dBm)
RN Site Acquisition and Deployment	4	CAPEX
RN Site Rent, Maintenance and Power	15.6	OPEX / no back-up batteries

4.4.1.2 Conclusion and discussion

The conclusion of the simulations for the relaying concept validation in a metropolitan particular scenario is clear; the inclusion of relays in the simulated scenario would be beneficial from a network costs point of view whenever the total costs of the relay used in the simulations be lower than the half costs of a sector included in the micro BS. Of course we should include all kind of costs (CAPEX and OPEX) and analyze the peculiarities of the scenario, for example availability of transmission lines and prices, in order to make a proper evaluation for deciding the best economical option.

Finally although we have estimated a cost ratio between micro BS with two sectors and RN near to 4 (coming from the relay-based configuration including RECs in two streets) for making a decision of what deployment to use, we could extrapolate the results at the whole of the deployment, using RECs in all the streets (1.6 times more efficient than a BS), so that the BS/RN costs ratio would be around 3 instead of 4.

4.4.2 Cost/performance comparison for selected relay and BS only deployments

Unfortunately in the MA CG scenario the possible positions of the RAPs are limited (in streets or at street crossings). Therefore the BS and RN density cannot be varied by the required granularity to perform an indifference curve analysis. However we can compare the cost and the performance of selected RN deployments to selected BS only deployments.

The deployment pattern of the selected BS only deployments are illustrated in Figure 4-5 to Figure 4-11. BSs in streets are equipped with 2 sectors, whereas BSs at the street crossings are equipped with 4 sectors each. The numbers in the brackets denote the amount of BS in the whole simulated Manhattan grid and will be used as an identifier of the scenarios in the analysis.

Figure 4-12 to Figure 4-17 illustrate the deployment pattern of selected relay deployments, where RNs have been added to the BS only deployments presented in Figure 4-5, Figure 4-8, Figure 4-9, and Figure 4-10. The RN associate with the closest BS and each BS sector has one associated RN, except for the scenario shown in Figure 4-12 and Figure 4-15 where only one of the two BS sectors has an associated RN.

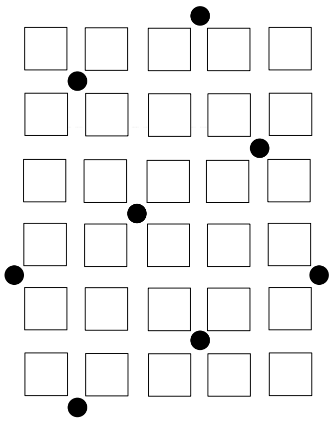


Figure 4-5 BS only deployment at crossing with 4 sectors per BS (128Sec)

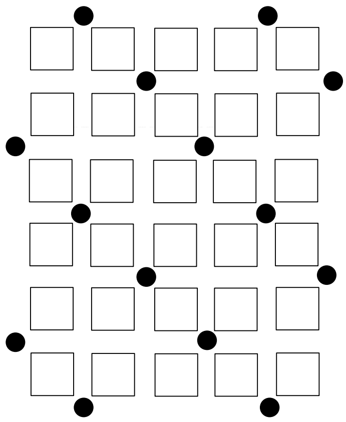


Figure 4-6 BS only deployment at crossing with 4 sectors per BS (208Sec)

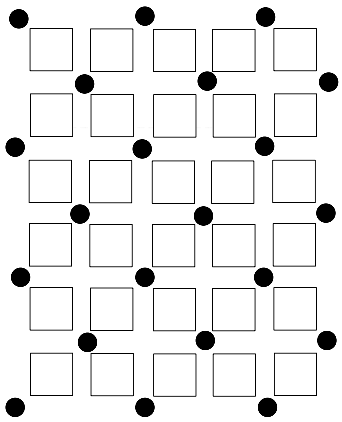


Figure 4-7 BS only deployment at crossing with 4 sectors per BS (312Sec)

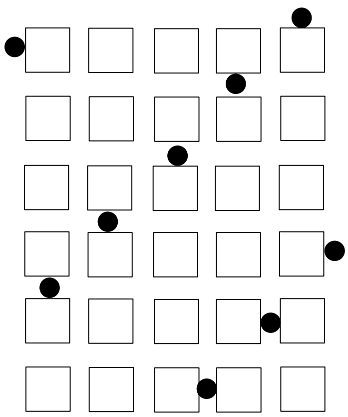


Figure 4-8 BS only deployment in street with 2 sectors per BS (72Sec)

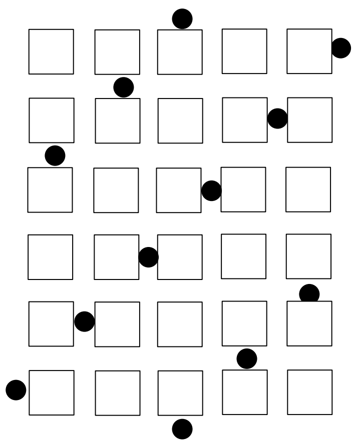


Figure 4-9 BS only deployment in street with 2 sectors per BS (96Sec)

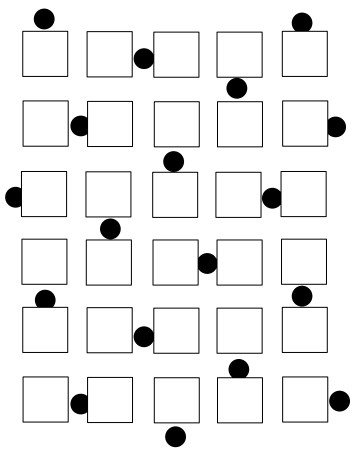


Figure 4-10 BS only deployment in street with 2 sectors per BS (144Sec)

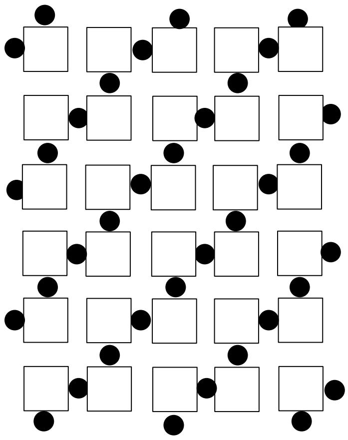


Figure 4-11 BS only deployment in street with 2 sectors per BS (286Sec)

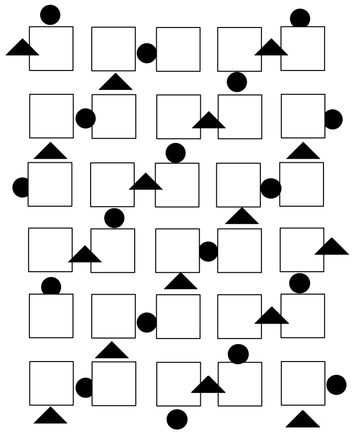


Figure 4-12 Relay deployment in street with 1RN for BS sector pointing down or to the right (144Sec 72RN)

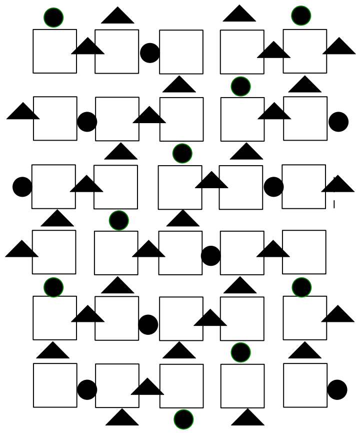


Figure 4-13 Relay deployment in street with 1 RN for each BS sector (144Sec 144RN)

For the comparison of the different deployments we use the example cost figures provided in [WIN2D61313] which are based on [JFK+04] and [TONIC11]. The capital expenditure (CAPEX) of the RN has been assumed to be comparable to a pico BS (2.1k€), for the 2 sector BS in the street we assume an increased hardware costs of 2.5k€ for the additional sector compared to a pico BS. Further, we assume the same site acquisition costs than for a micro BS, resulting in a CAPEX of 10.5k€ for the BS in the street. The deployment of the 4 sector BS at the street crossings is more challenging and 4 sectors increase the hardware costs. Therefore we assume the full price of a micro BS for these deployments of 13.5k€. Similarly we assume the same operational expenditure (OPEX) for the RN than for a pico BS which sums up to 3.9k€ over 10 years excluding the cost for the backhaul connection. The OPEX for the BS in the street include additionally the costs of the fixed line connections and the overall OPEX sum up to 10.14k€ over 10 years. For the 4 sector BS at the street crossing we assume the same OPEX than for a micro BS of 29.5k€ over 10 years. Thus, the costs over 10 years are assumed to be 6k€ per RN, 20.64k€ for the 2 sector BS in the street and 43k€ for the 4 sector BS at the street crossing, respectively.

We compared the different deployment options in dynamic system simulations using the same simulation parameters as described in Section 2.3. The user density is kept constant in all simulations and we evaluate the performance indicators only from the monitored centre cells. The amount of monitored cells has been chosen such to get a comparable monitored area for each scenario. It varies between two cells for the scenario illustrated in Figure 4-14 to 8 cells for the scenario presented in Figure 4-11. To get comparable results, the throughput and the costs have been normalized over an area of 1sqkm.

We use the same resource partitioning and deployment options described in Section 3.3.1 to optimize the performance of each deployment. First, we run simulations with and without directive antennas at the RN. Further, we test whether a scenario with RN and BS transmitting at the same time outperforms a scenario where RN and BS transmit in different time slots. Finally, we also find the optimal number of frames in which the RN should be allowed to transmit. After exploring all these resource partitioning options for each scenario, we pick the best performing combination and use it for the comparison of the different scenarios.

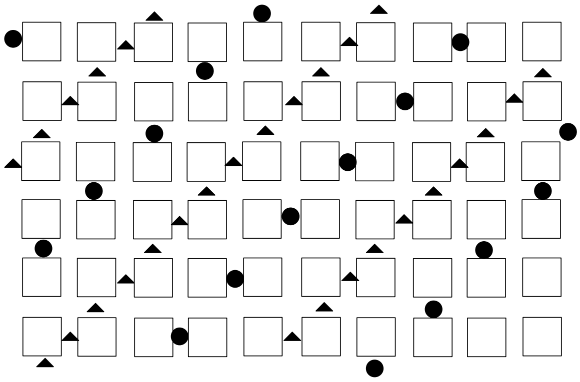


Figure 4-14 Relay deployment in street with 1 RN per BS sector (72Sec 72RN)

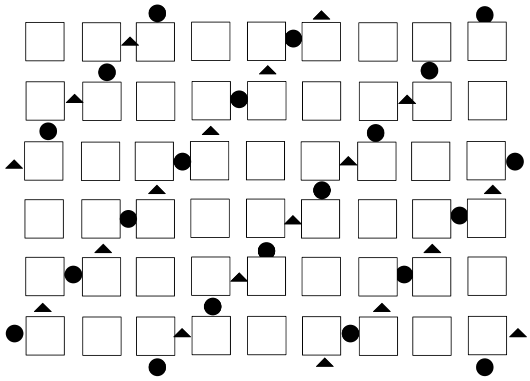


Figure 4-15 Relay deployment in street with 1RN for BS sector pointing down or to the right (96Sec 48RN)

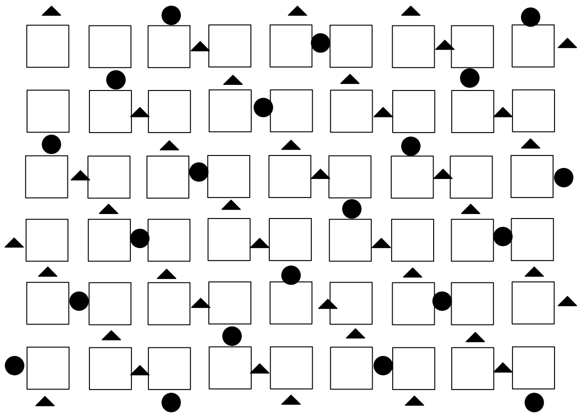


Figure 4-16 Relay deployment in street with 1 RN per BS sector (96Sec 96RN)

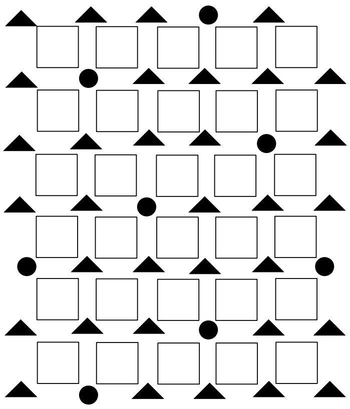


Figure 4-17 Relay deployment at crossing with 1 RN for each BS sector (128Sec 128RN)

The outcome of this comparison is illustrated in Table 4-5. The scenarios are sorted by their average area throughput starting with the scenario that has the highest average throughput per sqkm. To select the most cost efficient deployment option for a given target performance, the cheapest deployment option that can meet the performance target has to be chosen. For example when an area throughput of 800 MByte/s/sqkm is targeted, the relay deployment in the street with a single RN for each 72 BS site (144 sectors) is the most cost efficient deployment. The next best BS only deployment has about 7% higher costs per sqkm and year.

Table 4-5 Scenario comparison: the average throughput and the cost have been normalized per area.

No.Sectors No.RN	286	312	208	144 72	144 144	128	144	128 128	96 96	96	96 48	72 72	72
Average Throughput in MB/s/sqkm	1534	1354	834	808	800	760	713	634	586	568	520	391	389
Cost in k€/sqkm/year	138	143	95	89	109	57	69	89	73	46	59	54	34

4.4.2.1 Discussion

The comparison of the different deployment scenarios illustrates that relay deployments can be more cost efficient than BS only deployments. If the target throughput is for example 800MB/s/sqkm, the RN deployment is 7% cheaper than the next BS only deployment that can meet this target. The cost figures used in the comparison take both capital and operational expenditures over 10 years into account and result in less than one third of the costs for a RN than for a 2 sector micro BS with reduced power, deployed in the street. Only outdoor users have been included in this comparison and it is fairly easy to build coverage even with a few number of radio access points. In our future work we will also include indoor users which will make it more difficult to build coverage. We expect that the use of RNs can be even more beneficial in that case. Further, it can be observed that especially the relay deployments based on 96 and 72 BS sectors do not show much improvement compared to the BS only deployment. Even though the deployment in these scenarios is sparser, the RN still have the next RAP around the corner. Especially in these scenarios the use of interference coordination schemes such as soft frequency reuse might further increase the performance and in our future work we will also include this aspect in the cost comparison.

4.5 Summary and conclusion

In this chapter, we have described an extension to the cost methodology based on indifference or iso-performance curves introduced in earlier deliverables. In particular, we have shown how the methodology can be applied to find the optimum deployment, taking into account both uplink and downlink. We have also presented results from simulations using this methodology, both for variable traffic density and for a real geographic area of Madrid. From these, we conclude that the inclusion of RNs in a network deployment can have a beneficial impact on the overall cost of a network, provided that the cost of a RN is less than approximately 1/3rd that of a BS. Further work is, however, required to extend the range of results to determine the optimum least-cost configuration. Application of the methodology to the MA environment is proving problematic, due to the limited area and the coarse granularity of the deployment, and further work is also required to resolve this issue. However studying a selected set of deployment scenarios, we can conclude that relay deployments can offer a cost benefit compared to a BS only deployment with a cost of a RN of a bit less than 1/3rd that of a BS.

5 Conclusions

The focus of this document is to apply methodologies for performance and cost assessment to relay based deployment. We clearly show how relaying solution outperforms base stations only deployment. Moreover results demonstrate the applicability of relaying concept to a whole range of different conditions ranging from indoor to wide area suburban scenarios.

In particular, the e2e performance assessment is conducted according to the methodology identified in [WIN2D6137] and in the concept groups [WIN2D6133-5]. The following assessment criteria have been measured: spectral efficiency, maximum number of supported users and delay once the satisfied user criterion is being met, as defined in [WIN2D6137]. The Satisfied User Criterion (SUC) is defined as an average active session throughput of 2Mbps or higher needs to be guaranteed for 95 percentile of users in downlink and an average active session throughput of 1.3Mbps or higher needs to be guaranteed for 95 percentile of users in the uplink. Moreover, the cost assessment methodology illustrated in [WIN2D352] section A.3 has driven the cost assessment.

The performance of baseline scenarios in chapter 2, as defined in [WIN2D6137], serves for comparison purpose of different simulators. The baseline scenarios have not been optimized and therefore performance improvement due to relaying with respect to BS only deployment are not always achieved. Further improvements are expected using the reference design, as shown in chapter 3. In contrast to the baseline design it describes technology options that optimize the performance of relay based deployments in each concept group scenario.

The main motivation to deploy RNs is to decrease the overall network cost while maintaining a required service level. Therefore in chapter 4 we have extended the methodology based on iso-performance curves illustrated in [WIN2D352] for single direction (or equivalently single service) to include both uplink and downlink (or equivalently multiple services). Moreover, extensive simulation campaign have shown that relay deployments are more cost efficient, assuming a cost ratio for RN of 1/3rd that of a BS.

The refinement of WIINER relaying concept will be performed combining contributions from all previous deliverables, both in phase I and II of the project, and will be delivered in a separate document at the end of the project.

6 Acronyms

3GPP	3rd Generation Partnership Project
AC	Admission Control
ACK	ACKnowledgment
ARQ	Automatic Repeat reQuest
AWGN	Additive White Gaussian Noise
BCH	Broadcast Channel
BER	Bit Error Rate
BLER	Block Error Rate
BS	Base Station
BW	BandWidth
CAPEX	Capital Expenditures
CDF	Cumulative Distribution Function
CCB	Chunk-by-Chunk Balancing
CG	Concept Group
CRC	Cyclic Redundancy Check
CSI	Channel State Information
DCH	Dedicated Channel
DL	Downlink
DoA	Direction of Arrival
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transform
HARQ	Hybrid Automatic Repeat reQuest
HSDPA	High Speed Downlink Packet Access
IP	Internet Protocol
ISD	Inter-Site distance
IIB	Iterative Independent Balancing
L{x}	Layer x=1,2,3
LTE	Long-Term Evolution
MA	Metropolitan Area
MAC	Medium Access Control
MBMS	Multimedia Broadcast / Multicast Services
MIMO	Multiple-Input Multiple-Output
MUD	Multi-User Detection
NACK	Negative ACKnowledgement
NLOS	None LOS
OFDM	Orthogonal Frequency Division Multiplexing

OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditures
P2P	Peer-to-Peer
PARC	Per Antenna Rate Control
PDU	Protocol Data Unit
PER	Packet Error Rate
PF	Proportional Fair
PHY	Physical Layer
PLM	Physical Layer Mode
QoS	Quality-of-Service
RACK	Relay ACKnowledgement
RAN	Radio Access Network
RAP	Radio Access Point
RAT	Radio Access Technology
RAU	Resource Allocation Unit
RB	Radio Bearer
RCDD	Relay Cyclic Delay Diversity
REACT	Routing information Enhanced Algorithm for Cooperative Transmission
REC	Relay Enhanced Cell
RLC	Radio Link Control
RN	Relay Node
RRC	Radio Resource Control
RRM	Radio Resource Management
RS	Resource Scheduler
RTT	Round Trip Time
SA	Services and Architecture
SAP	Service Access Point
SAR	Segmentation and Reassembly
SDM	Space Division Multiplexing
SDMA	Space Division Multiple Access
SDU	Service Data Unit
SH	Single-Hop
SIR	Signal-to-Interference Ratio
SLC	Service Level Controller
SINR	Signal-to-Interference Noise Ratio
SISO	Single-Input Single-Output
SNR	Signal-to-Noise Ratio
STTD	Space-Time Transmit Diversity
SUD	Single-User Detection
TB	Transport Block

TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDMA	Time-Division Multiple Access
Tx/Rx	Transmit / Receive
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UT	User Terminal
UTRA	Universal Terrestrial Radio Access
VAA	Virtual Antenna Array
WA	Wide Area
WCDMA	Wideband Code Division Multiple Access
WINNER	WWI New Radio IP
WLAN	Wireless Local Area Network

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